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BUREAU OF PUBLIC ROADS

D. M. BEACH, *Editor*

Volume 20, No. 2 April 1939

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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EXPERIMENTAL BITUMINOUS-TREATED SURFACES ON SAND-CLAY AND MARL BASES

REPORT ON EXPERIMENTS IN SOUTH CAROLINA

Reported by **PAUL F. CRITZ**, Associate Highway Engineer, U. S. Bureau of Public Roads, and
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A BITUMINOUS TREATED EXPERIMENTAL ROAD was built in Berkeley County, South Carolina, in 1929 by the State highway department and the Bureau of Public Roads to obtain information on sand-clay and marl as base materials and on the comparative value of various bituminous materials and methods of construction. This experimental road is still in service and a considerable portion of it is in good condition at the present time. It has been maintained with only such changes as have been brought about by the application of necessary re-treatments and maintenance that have been required to keep it in reasonably good condition at all times. The record of its construction, maintenance, and service behavior, provides an opportunity for the study of a number of factors upon which information was desired.

The experimental road, 4.48 miles long, was constructed on State route 46 and extends from the intersection with United States Highway No. 52 at Moncks Corner to the village of Pinopolis. It consists of eight different sections constructed upon a marl base and eight corresponding sections built upon a sand-clay base. Three methods of construction were employed in building the bituminous surfaces. One was the mixed-in-place or road-mix method in which the aggregates and bituminous materials were mixed together on the road with blade graders and then spread and rolled. The second was the penetration method in which the aggregate was spread and rolled and then penetrated with the bituminous material. The third method was the surface-treatment type, sometimes referred to as inverted penetration, in which the bituminous material was spread first and immediately covered with aggregate. Except on the road-mix sections, no manipulation other than that of light brooming to obtain a uniform cover of aggregate was done. Rolling completed the operations except where a seal was applied.

All of the bituminous materials used were liquid and were warmed slightly to insure uniform application. The material used for priming both the marl and sand-clay bases was a tar of 8 to 13 specific viscosity at 40° C. The materials used as binders in the mixed mats were a tar of 25 to 35 specific viscosity, Engler, at 40° C. and two asphalt cements of 60–70 and 85–100 penetration, respectively, cut-back with naphtha. These two asphaltic materials will be referred to as 60–70 or 85–100 "cut-backs" or "CB." A quick-breaking emulsion was used in the penetration sections and an 85–100 cut-back was used in the surface-treated sections. For the seal treatments, the same bituminous material used as a binder in a given section was used except in section 6A

TABLE 1.—*Analyses of subgrade and base course materials*

Identification of samples				Mechanical analysis						Characteristics of materials passing No. 40 sieve							Soil group
													Shrinkage		Moisture equivalent		
Section	Date sampled	Laboratory No.	Material represented	Particles larger than 2.0 mm.	Coarse sand, 2.0 to 0.25 mm.	Fine sand, 0.25 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, smaller than 0.005 mm.	Colloids, smaller than 0.001 mm.	Per cent passing	Liquid limit	Plasticity index	Limit	Ratio	Centrifuge	Field	
				Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*								
1A and 1B.	1934	8166	Subgrade	0	33	39	13	15	17	94	13	3	12	2.0	12	12	A–2, feebly plastic.
2A	1936	10134	do	0	32	33	14	21	--------	82	28	14	14	1.8	17	18	A–2, plastic.
2C	1934	8162	do	0	32	29	13	26	20	83	27	16	13	1.9	18	18	Do.
2C	1936	10139	do	0	9	50	22	19	--------	96	34	18	15	1.8	19	21	A–4, very plastic.
3	1934	8163	do	0	35	49	5	11	10	89	16	0	------	------	6	19	A–3.
3	1936	10136	do	0	42	34	9	15	--------	88	16	1	11	1.9	7	17	A–2, friable.
4	1934	8164	do	0	36	45	7	12	8	86	14	0	------	------	9	17	A–3.
2A	1936	10133	Marl base	0	12	45	21	22	--------	95	40	9	------	------	23	-------	A–5.
2C	1934	8161	do	0	11	44	21	24	15	95	40	17	31	1.4	29	31	A–5.
2C	1936	10138	do	0	14	48	19	19	--------	95	41	6	31	1.4	23	42	A–5.
3	1936	10135	do	0	14	44	21	21	--------	94	35	9	27	1.5	21	29	A–2, plastic.
3	1936	10137	do	0	14	48	19	19	--------	95	36	5	27	1.5	19	33	A–4.
5	1936	10140	do	0	13	47	20	20	--------	94	38	7	32	1.4	21	35	A–5.
6A [1]	During construction	--------	Sand-clay base	1	17–24	47–53	10–11	19	14–15	93	25–26	9–12	17	1.8	14–16	19–22	A–2.
6B [2]	do	--------	do	0–1	24–30	43–46	8–11	16–21	11–15	89–93	21–28	8–12	18	1.8	14–20	17–23	A–2.
7A [3]	do	--------	do	0–1	21–30	46–60	7–8	11–17	7–14	92–93	17–24	0–10	17	1.8	8–14	16–20	A–2 and A–3.
7A	1934	8165	do	0	32	50	6	12	7	93	17	0	------	------	9	17	A–3.
7B [3]	During construction.	--------	do	0–1	19–27	55–59	8	10–14	7–11	95	18–21	0–7	17–18	1.8	11–16	16–17	A–1 and A–2.
8	1934	8168	do	0	29	55	4	12	8	93	15	0	------	------	8	19	A–3.
10 [2]	During construction.	--------	do	0	12–20	50–65	8–11	11–21	8–16	94–95	17–30	0–16	17–18	1.8	9–18	17–19	A–2 and A–3.
10	1934	8167	do	0	26	51	7	16	12	96	19	7	15	1.9	11	16	A–2 plastic.

[1] 2 samples.

[2] 4 samples.

[3] 3 samples.

where an 85–100 cut-back was used to seal the mat in which a 60–70 cut-back had been used as the binder. All of the asphaltic materials came from one refinery; all of the tar products came from another.

The aggregate was crushed granite graded as follows: 1¼ to ¼ inch, ¾ to ¼ inch, ⅝ to ¼ inch, and ¼ inch to dust.

ANALYSIS OF MATERIALS AND COST GIVEN FOR EACH SECTION

The location and description of the various sections comprising the experiment are shown in the charts in figures 1 and 2, which also show the character and extent of the re-treatments that have been applied since construction. Analyses of the base and subgrade materials are given in table 1. The grading of the aggregates and the analyses of the bituminous materials used are given in tables 2, 3, 4, and 5. The cost of maintaining the bituminous surfaces, including re-treatments, is given in table 6.

TABLE 2.—*Mechanical analysis of crushed stone used in construction*

Size designation	1¼ to ¼ inch	¾ to ¼ inch	⅝ to ¼ inch	¼ inch to dust
Retained on—	*Percent*	*Percent*	*Percent*	*Percent*
1¼-inch screen				
1-inch screen	16			
¾-inch screen	39			
½-inch screen	63	6	1	
¼-inch screen	88	59	71	
No. 10 sieve	100	88	96	15
No. 20 sieve		95	99	48
No. 30 sieve		100	100	59
No. 40 sieve				70
No. 50 sieve				79
No. 80 sieve				89
No. 100 sieve				92
No. 200 sieve				97

The experimental road extends west and north from the intersection with United States Highway No. 52 at Moncks Corner, where the stationing begins, but for easy reference in this report it will be considered as extending from east to west.

The route on which the improvement was made carries principally passenger cars and light trucks, but some heavier trucks with trailers carrying relatively heavy loads of logs or merchandise also use it. The average daily traffic is given in table 7. The area adjoining the experimental road is relatively flat and low with the water table close to the surface. The soil is sandy loam, suitable for agricultural purposes and forms the subgrade of the roads in this area. Unsurfaced roads in the vicinity contain the same type of soil and their service behavior depends upon the composition of the soil. The subgrade on the experimental road was composed of material of this character and, as shown in table 1, varied somewhat in composition and physical characteristics. Some natural drainage is afforded and this has been supplemented since construction by the installation of cross drains, French drains, and side ditches so that the drainage requirements have in general been fairly well met.

At the time this experimental road was constructed, the application of present-day soil analysis had not reached the stage of development that it has more recently attained. Methods of stabilizing loosely bonded, sandy soils had been developed and a considerable amount of work of this character had been done in South Carolina and elsewhere both experi-

TABLE 3.—*Composition of the cut-back asphalts used in construction*

ANALYSIS OF DISTILLATE

Specific gravity, 77°/77° F	0.786
Initial boiling point ° F	172
Total distillate to 200° F percent	2
Total distillate to 300° F do	16
Total distillate to 392° F do	89
End point ° F	522

ANALYSIS OF ASPHALT CEMENT BASE

	Penetration grade, 60 to 70	Penetration grade, 85 to 100
Penetration at 77° F	67	100
Softening point ° F	125	116
Ductility at 77° F cm	110+	110+
Loss at 325° F., 5 hours, 50 grams percent	.01	.02
Solubility in CS_2 do	99.88	99.88

ANALYSIS OF COMBINED DISTILLATE AND BASE

	Penetration grade, 60 to 70	Penetration grade, 85 to 100
Specific gravity at 77°/77° F	0.947– 0.950	0.942– 0.947
Flash point ° F	82 – 86	77 – 86
Specific viscosity, Engler, at 104° F	59 – 71	41 – 62
Specific viscosity, Engler, at 122° F	30 – 37	23 – 34
Loss, 325° F., 5 hours, 50 grams percent	25.4 – 28.3	24.5 – 28.2
Residue, penetration at 77° F	84 –101	104 –119
Loss, 325° F., 5 hours, 20 grams percent	26.3 – 29.8	24.9 – 25.9
Residue, penetration at 77° F	44 – 50	56 – 65
Solubility in CS_2 percent	99.79 – 99.91	99.79 – 99.88
Organic matter insoluble do	.18 – .08	.18 – .07
Inorganic matter insoluble do	.03 – .01	.04 – .02
Bitumen insoluble in 86° B. naphtha do	18.8 – 19.4	14.9 – 17.0
Residue of 100 penetration do	72 – 73	74 – 75
Penetration of residue at 77° F	87 – 94	90 –104
Penetration of residue at 32° F	14 – 23	12 – 22
Softening point of residue ° F	115 –126	115 –119
Ductility of residue at 77° F cm	110+	110+
Ductility of residue at 38° F do	4.0 – 5.2	4.9 – 6.4
Distillation by volume (A. S. T. M. D402–36):		
Total distillate to 374° F percent	6.0 – 9.8	0.8 – 11.5
Total distillate to 437° F do	19.0 – 25.0	20.0 – 22.0
Total distillate to 680° F do	30.6 – 37.4	29.7 – 33.6
Residue, penetration at 77° F	67 – 75	78 – 98
Residue, softening point ° F	119 –122	110 –118

TABLE 4.—*Analysis of tars used in construction*

	Grade of material	
	8–13 viscosity [1]	25–35 viscosity[2]
Specific gravity, 77°/77° F	1.142– 1.148	1.165
Specific viscosity, Engler, at 104° F	11.1 – 11.7	27.5 – 28.5
Solubility in CS_2 percent	96.15 – 96.93	95.92 – 96.98
Organic matter insoluble do	2.65 – 3.81	2.04 – 3.61
Inorganic matter insoluble do	.02 – .04	.02 – .07
Water do	.04 – —	.40 – .96
Distillation by weight, water-free basis:		
To 338° F percent	1.05 – 1.25	.53 – 1.07
338°–455° F do	6.67 – 6.93	4.71 – 5.29
455°–518° F do	11.57 – 11.89	8.89 – 10.26
518°–572° F do	8.40 – 8.45	7.89 – 8.03
Residue do	71.49 – 72.10	76.07 – 77.26
Softening point of residue ° F	109 –110	106 –107

[1] Used as a prime on all sections.
[2] Used on secs. 2B and 7B in the mixture and in the seal coat.

TABLE 5.—*Analysis of asphalt emulsion used in the construction of sections 2C and 7C*

Specific gravity, 77°/77° F	1.009
Specific viscosity, Engler, at 122° F	1.98
Distillation to 500° F., by weight:	
Water percent	47.3
Oil do	Trace
Residue do	52.6
Tests on residue from distillation:	
Specific gravity, 77°/77° F	1.015
Penetration at 77° F	113
Softening point ° F	118
Ductility at 77° F cm	96.5
Solubility in CS_2 percent	98.94
Organic matter insoluble do	.40
Ash (by ignition) do	.66

TABLE 6.—*Cost of construction, re-treatments, and maintenance of the various experimental sections to July 1, 1937*

Section			Type of base	Construction					Annual cost per square yard of re-treatments and maintenance of bituminous surfaces only																	
No.	Station			Mat			Seal	Cost per square yard	1929-30		1930-31		1931-32		1932-33		1933-34		1934-35		1935-36		1936-37		Total	Average annual cost
	From	To		Bituminous material	Size of aggregate	Method of construction	Bituminous material[1]		Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment		
								Cts.	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*
1-A	0+00	13+28	Marl	Asphalt, cut-back	1¼ inch to dust	Road-mix	Asphalt, cut-back	66.12	0.48	-----	1.56	-----	1.40	10.55	0.43	-----	0.31	-----	0.14	-----	0.23	9.53	1.12	-----	25.75	3.32
1-B	13+28	24+50	do	do	do	do	do	72.58	1.37	-----	7.75	[3] 5.73	2.57	[3] 7.95	.60	[3] 1.76	.84	-----	.29	-----	-----	10.03	.81	[3] 2.59	42.29	5.46
2-A	[2] 24+50	39+60	do	do	1¼-¼ inch	do	do	70.34	.18	-----	3.86	-----	5.46	7.82	.65	[3] 2.20	.63	-----	.52	-----	1.91	10.28	1.33	13.89	48.73	6.29
2-B	39+60	52+00	do	Tar	do	do	Tar	79.40	1.36	-----	3.80	[3] 5.50	8.87	[3] 11.23	.96	[3] 3.33	.62	-----	.82	-----	-----	15.25	.86	[3] 2.82	55.42	7.15
2-C	52+00	66+00	do	Asphalt emulsion	1¼ inch to dust	Penetration	Asphalt emulsion	84.62	2.61	-----	8.95	[3] 13.28	12.43	[3] 21.45	2.57	[3] 4.09	.89	[3] 5.98	.07	-----	2.73	[3] 6.49	2.71	19.61	103.86	13.40
3	79+20	92+40	do	Asphalt, cut-back	¾ inch to dust	Road-mix	-----	61.07	.39	-----	.08	-----	.17	-----	.87	-----	-----	-----	-----	-----	1.36	-----	.18	14.34	17.39	2.24
4	92+40	105+84	do	do	¾-¼ inch	do	Asphalt, cut-back	55.46	1.16	-----	1.37	-----	1.11	[3] 4.52	.57	-----	1.20	-----	1.26	-----	1.06	10.55	.89	-----	23.69	3.06
5	66+00	79+20	do	do	1¼-¼ inch	Surface treatment.	do	28.47	3.60	(4 5)	4.06	-----	1.97	[3] 4.51	2.29	-----	.03	[3] 7.38	.72	-----	.74	-----	.13	14.34	39.77	5.13
6-A	105+84	119+99	Sand-clay.	do	1¼ inch to dust	Road-mix	do	72.53	.48	-----	.05	-----	.59	-----	.65	-----	-----	12.20	.14	-----	-----	-----	-----	-----	14.11	1.82
6-B	119+99	132+00	do	do	do	do	do	72.10	.62	-----	1.68	-----	2.93	9.51	.38	-----	-----	-----	-----	-----	-----	-----	-----	-----	15.12	1.95
7-A	132+00	144+20	do	do	1¼-¼ inch	do	do	62.86	1.24	-----	2.00	-----	3.85	12.65	.20	-----	-----	-----	-----	-----	-----	-----	.35	-----	20.29	2.62
7-B	199+70	212+90	do	Tar	do	do	Tar	73.23	1.18	(4 5)	1.45	-----	1.77	-----	.93	-----	-----	-----	-----	-----	2.90	-----	.70	17.98	26.91	3.47
7-C	144+20	158+40	do	Asphalt emulsion	1¼ inch to dust	Penetration	Asphalt emulsion	84.55	1.02	-----	.54	-----	3.45	18.10	.33	-----	-----	-----	-----	-----	.90	-----	.48	19.37	44.19	5.70
8	212+90	226+10	do	Asphalt, cut-back	¾ inch to dust	Road-mix	-----	59.53	.37	-----	.05	-----	.80	-----	.04	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.26	.16
9	226+10	238+80	do	do	¾-¼ inch	do	Asphalt, cut-back	66.74	.56	-----	.42	-----	1.61	-----	.30	-----	-----	-----	-----	-----	.03	-----	-----	-----	2.92	.38
10	[6] 158+40	199+70	do	do	1¼-¼ inch	Surface treatment.	-----	29.44	1.06	(5)	1.83	-----	.40	12.50	.28	-----	.04	-----	-----	-----	.03	-----	-----	-----	16.14	2.08

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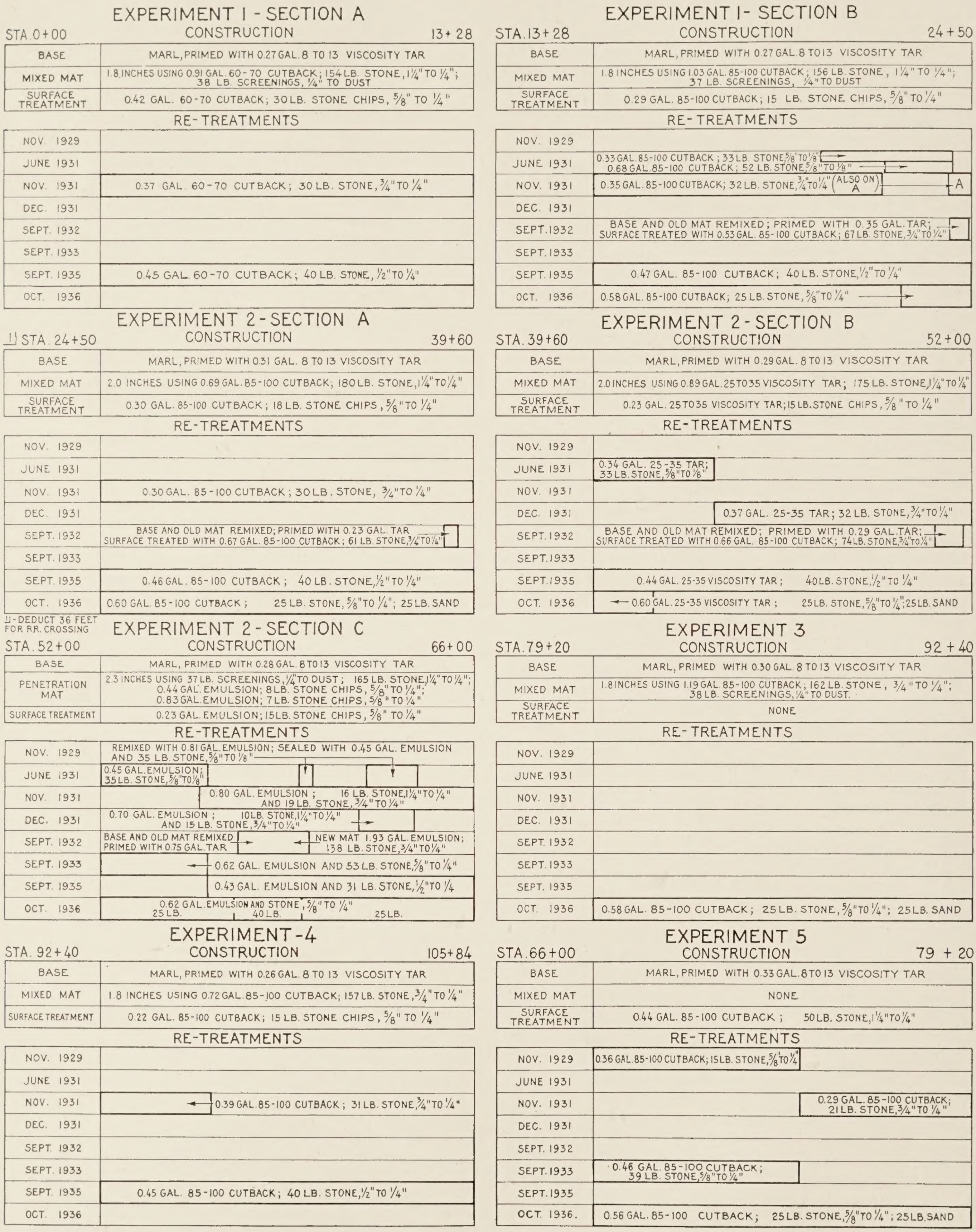
[1] Same type of material as used in the mixed mat, penetration or surface treatment course.
[2] Deduct 36 linear feet for railroad crossing.
[3] Treatment applied to part of section only but cost is prorated over entire section.
[4] Applied to part of section only.
[5] Cost included in construction cost.
[6] Deduct 170 linear feet for station correction.



EXPERIMENT 1 - SECTION A

STA. 0+00 CONSTRUCTION 13+28

BASE	MARL, PRIMED WITH 0.27 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 0.91 GAL. 60-70 CUTBACK; 154 LB. STONE, 1¼" TO ¼"; 38 LB. SCREENINGS, ¼" TO DUST
SURFACE TREATMENT	0.42 GAL. 60-70 CUTBACK; 30 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.37 GAL. 60-70 CUTBACK; 30 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	0.45 GAL. 60-70 CUTBACK; 40 LB. STONE, ½" TO ¼"
OCT. 1936	

EXPERIMENT 1 - SECTION B

STA. 13+28 CONSTRUCTION 24+50

BASE	MARL, PRIMED WITH 0.27 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 1.03 GAL. 85-100 CUTBACK; 156 LB. STONE, 1¼" TO ¼"; 37 LB. SCREENINGS, ¼" TO DUST
SURFACE TREATMENT	0.29 GAL. 85-100 CUTBACK; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	0.33 GAL. 85-100 CUTBACK; 33 LB. STONE, ⅝" TO ⅛" 0.68 GAL. 85-100 CUTBACK; 52 LB. STONE, ⅝" TO ⅛"
NOV. 1931	0.35 GAL. 85-100 CUTBACK; 32 LB. STONE, ¾" TO ¼" (ALSO ON A) A
DEC. 1931	
SEPT. 1932	BASE AND OLD MAT REMIXED; PRIMED WITH 0.35 GAL. TAR; SURFACE TREATED WITH 0.53 GAL. 85-100 CUTBACK; 67 LB. STONE, ¾" TO ¼"
SEPT. 1933	
SEPT. 1935	0.47 GAL. 85-100 CUTBACK; 40 LB. STONE, ½" TO ¼"
OCT. 1936	0.58 GAL. 85-100 CUTBACK; 25 LB. STONE, ⅝" TO ¼"

EXPERIMENT 2 - SECTION A

[1] STA. 24+50 CONSTRUCTION 39+60

BASE	MARL, PRIMED WITH 0.31 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	2.0 INCHES USING 0.69 GAL. 85-100 CUTBACK; 180 LB. STONE, 1¼" TO ¼"
SURFACE TREATMENT	0.30 GAL. 85-100 CUTBACK; 18 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.30 GAL. 85-100 CUTBACK; 30 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	BASE AND OLD MAT REMIXED; PRIMED WITH 0.23 GAL. TAR SURFACE TREATED WITH 0.67 GAL. 85-100 CUTBACK; 61 LB. STONE, ¾" TO ¼"
SEPT. 1933	
SEPT. 1935	0.46 GAL. 85-100 CUTBACK; 40 LB. STONE, ½" TO ¼"
OCT. 1936	0.60 GAL. 85-100 CUTBACK; 25 LB. STONE, ⅝" TO ¼"; 25 LB. SAND

[1] - DEDUCT 36 FEET FOR R.R. CROSSING

EXPERIMENT 2 - SECTION B

STA. 39+60 CONSTRUCTION 52+00

BASE	MARL, PRIMED WITH 0.29 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	2.0 INCHES USING 0.89 GAL. 25 TO 35 VISCOSITY TAR; 175 LB. STONE, 1¼" TO ¼"
SURFACE TREATMENT	0.23 GAL. 25 TO 35 VISCOSITY TAR; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	0.34 GAL. 25-35 TAR; 33 LB. STONE, ⅝" TO ⅛"
NOV. 1931	
DEC. 1931	0.37 GAL. 25-35 TAR; 32 LB. STONE, ¾" TO ¼"
SEPT. 1932	BASE AND OLD MAT REMIXED; PRIMED WITH 0.29 GAL. TAR; SURFACE TREATED WITH 0.66 GAL. 85-100 CUTBACK; 74 LB. STONE, ¾" TO ¼"
SEPT. 1933	
SEPT. 1935	0.44 GAL. 25-35 VISCOSITY TAR; 40 LB. STONE, ½" TO ¼"
OCT. 1936	0.60 GAL. 25-35 VISCOSITY TAR; 25 LB. STONE, ⅝" TO ¼"; 25 LB. SAND

EXPERIMENT 2 - SECTION C

STA. 52+00 CONSTRUCTION 66+00

BASE	MARL, PRIMED WITH 0.28 GAL. 8 TO 13 VISCOSITY TAR
PENETRATION MAT	2.3 INCHES USING 37 LB. SCREENINGS, ¼" TO DUST; 165 LB. STONE, 1¼" TO ¼"; 0.44 GAL. EMULSION; 8 LB. STONE CHIPS, ⅝" TO ¼"; 0.83 GAL. EMULSION; 7 LB. STONE CHIPS, ⅝" TO ¼"
SURFACE TREATMENT	0.23 GAL. EMULSION; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	REMIXED WITH 0.81 GAL. EMULSION; SEALED WITH 0.45 GAL. EMULSION AND 35 LB. STONE, ⅝" TO ⅛"
JUNE 1931	0.45 GAL. EMULSION; 35 LB. STONE, ⅝" TO ⅛"
NOV. 1931	0.80 GAL. EMULSION; 16 LB. STONE, 1¼" TO ¼" AND 19 LB. STONE, ¾" TO ¼"
DEC. 1931	0.70 GAL. EMULSION; 10 LB. STONE, 1¼" TO ¼" AND 15 LB. STONE, ¾" TO ¼"
SEPT. 1932	BASE AND OLD MAT REMIXED PRIMED WITH 0.75 GAL. TAR NEW MAT 1.93 GAL. EMULSION; 138 LB. STONE, ¾" TO ¼"
SEPT. 1933	0.62 GAL. EMULSION AND 53 LB. STONE, ⅝" TO ¼"
SEPT. 1935	0.43 GAL. EMULSION AND 31 LB. STONE, ½" TO ¼
OCT. 1936	0.62 GAL. EMULSION AND STONE, ⅝" TO ¼" 25 LB. 40 LB. 25 LB.

EXPERIMENT 3

STA. 79+20 CONSTRUCTION 92+40

BASE	MARL, PRIMED WITH 0.30 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 1.19 GAL. 85-100 CUTBACK; 162 LB. STONE, ¾" TO ¼"; 38 LB. SCREENINGS, ¼" TO DUST.
SURFACE TREATMENT	NONE

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	0.58 GAL. 85-100 CUTBACK; 25 LB. STONE, ⅝" TO ¼"; 25 LB. SAND

EXPERIMENT-4

STA. 92+40 CONSTRUCTION 105+84

BASE	MARL, PRIMED WITH 0.26 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 0.72 GAL. 85-100 CUTBACK; 157 LB. STONE, ¾" TO ¼"
SURFACE TREATMENT	0.22 GAL. 85-100 CUTBACK; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.39 GAL. 85-100 CUTBACK; 31 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	0.45 GAL. 85-100 CUTBACK; 40 LB. STONE, ½" TO ¼"
OCT. 1936	

EXPERIMENT 5

STA. 66+00 CONSTRUCTION 79+20

BASE	MARL, PRIMED WITH 0.33 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	NONE
SURFACE TREATMENT	0.44 GAL. 85-100 CUTBACK; 50 LB. STONE, 1¼" TO ¼"

RE-TREATMENTS

NOV. 1929	0.36 GAL. 85-100 CUTBACK; 15 LB. STONE, ⅝" TO ¼"
JUNE 1931	
NOV. 1931	0.29 GAL. 85-100 CUTBACK; 21 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	0.46 GAL. 85-100 CUTBACK; 39 LB. STONE, ⅝" TO ¼"
SEPT. 1935	
OCT. 1936.	0.56 GAL. 85-100 CUTBACK; 25 LB. STONE, ⅝" TO ¼"; 25 LB. SAND

FIGURE 1.—CHARACTER OF CONSTRUCTION AND RE-TREATMENTS APPLIED TO EXPERIMENTS 1 TO 5, INCLUSIVE. QUANTITIES SHOWN ARE AMOUNTS PER SQUARE YARD OF SURFACE AREA.

EXPERIMENT 6 - SECTION A

STA. 105+84 CONSTRUCTION 119+99

BASE	SAND-CLAY, PRIMED WITH 0.33 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	2.0 INCHES USING 1.0 GAL. 60-70 CUTBACK; 171 LB. STONE, 1¼" TO ¼"; 40 LB. SCREENINGS, ¼" TO DUST
SURFACE TREATMENT	0.34 GAL. 85-100 CUTBACK; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	
DEC. 1931	
SEPT. 1932	
SEPT. 1933	0.42 GAL. 60-70 CUTBACK; 40 LB. STONE, ⅝" TO ¼"
SEPT. 1935	
OCT. 1936	

EXPERIMENT 6 - SECTION B

STA. 119+99 CONSTRUCTION 132+00

BASE	SAND-CLAY, PRIMED WITH .0.39 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	2.0 INCHES USING 1.09 GAL. 85-100 CUTBACK; 170 LB. STONE, 1¼" TO ¼"; 42 LB. SCREENINGS, ¼" TO DUST
SURFACE TREATMENT	0.23 GAL. 85-100 CUTBACK; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.41 GAL. 85-100 CUTBACK; 21 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	

EXPERIMENT 7 - SECTION A

STA. 132+00 CONSTRUCTION 144+20

BASE	SAND-CLAY, PRIMED WITH 0.29 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	2.0 INCHES USING 0.77 GAL. 85-100 CUTBACK; 178 LB. STONE, 1¼" TO ¼"
SURFACE TREATMENT	0.27 GAL. 85-100 CUTBACK; 18 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.35 GAL. 85-100 CUTBACK; 35 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	

EXPERIMENT 7 - SECTION B

STA. 199+70 CONSTRUCTION 212+90

BASE	SAND-CLAY, PRIMED WITH 0.25 GAL. 8 TO 13 VISCOSITY TAR	
MIXED MAT	2.0 INCHES USING 0.77 GAL. 25 TO 35 VISCOSITY TAR; 169 LB. STONE, 1¼" TO ¼"	
SURFACE TREATMENT	← REMIXED WITH 0.30 GAL. 25 TO 35 VISCOSITY TAR →	← 0.42 GAL. 25 TO 35 VISCOSITY TAR; 15 LB. STONE CHIPS, ⅝" TO ¼" →

RE-TREATMENTS

NOV. 1929	0.23 GAL. 25 TO 35 VISCOSITY TAR; 15 LB. STONE CHIPS, ⅝" TO ¼"	
JUNE 1931		
NOV. 1931		
DEC. 1931		
SEPT. 1932		
SEPT. 1933		
SEPT. 1935		
OCT. 1936	0.60 GAL. 25 TO 35 VISCOSITY TAR; 25 LB. STONE, ⅝" TO ¼"; 25 LB. SAND	

EXPERIMENT 7 - SECTION C

STA. 144+20 CONSTRUCTION 158+40

BASE	SAND-CLAY, PRIMED WITH 0.34 GAL. 8 TO 13 VISCOSITY TAR
PENETRATION MAT	2.3 INCHES USING 1.11 GAL. EMULSION; 30 LB. SCREENINGS, ¼" TO DUST; 165 LB. STONE, 1¼" TO ¼"
SURFACE TREATMENT	0.25 GAL. EMULSION; 15 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	0.63 GAL. EMULSION; 37 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	0.89 GAL. EMULSION; 40 LB. STONE, ⅝" TO ¼"; 27 LB. SAND

EXPERIMENT 8

STA. 212+90 CONSTRUCTION 226+10

BASE	SAND-CLAY, PRIMED WITH 0.26 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 1.25 GAL. 85-100 CUTBACK; 154 LB. STONE, ¾" TO ¼"; 38 LB. SCREENINGS, ¼" TO DUST
SURFACE TREATMENT	NONE

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	

EXPERIMENT 9

STA. 226+10 CONSTRUCTION 238+80

BASE	SAND-CLAY, PRIMED WITH 0.27 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	1.8 INCHES USING 0.77 GAL. 85-100 CUTBACK; 152 LB. STONE, ¾" TO ¼"
SURFACE TREATMENT	0.29 GAL. 85-100 CUTBACK; 14 LB. STONE CHIPS, ⅝" TO ¼"

RE-TREATMENTS

NOV. 1929	
JUNE 1931	
NOV. 1931	
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	

EXPERIMENT 10

[1] STA. 158+40 CONSTRUCTION 199+70

BASE	SAND-CLAY, PRIMED WITH 0.29 GAL. 8 TO 13 VISCOSITY TAR
MIXED MAT	NONE
SURFACE TREATMENT	0.46 GAL. 85-100 CUTBACK; 52 LB. STONE, 1¼" TO ¼"

RE-TREATMENTS

NOV. 1929	0.32 GAL. 85-100 CUTBACK; APPROXIMATELY 25 LB. LOOSE SURFACE STONE AND 10 TO 13 LB. STONE, ¾" TO ¼"
JUNE 1931	
NOV. 1931	0.50 GAL. 85-100 CUTBACK; 46 LB. STONE, ¾" TO ¼"
DEC. 1931	
SEPT. 1932	
SEPT. 1933	
SEPT. 1935	
OCT. 1936	

[1] DEDUCT 170 FEET FOR STATION EQUATION

FIGURE 2.—CHARACTER OF CONSTRUCTION AND RE-TREATMENTS APPLIED TO EXPERIMENTS 6 TO 10, INCLUSIVE. QUANTITIES SHOWN ARE AMOUNTS PER SQUARE YARD OF SURFACE AREA.

Table 7.—*Average traffic on the experimental road, between 7 a. m. to 7 p. m.*

	Recording station	
	No. 1[1]	No. 2[2]
	Number	*Number*
Upon completion of project	587	320
1930 (average of 9 counts)	474	276
1931 (average of 12 counts)	537	325
1932 (average of 11 counts)	478	272
1933 (average of 12 counts)	572	320
1934 (average of 12 counts)	751	444
1935 (average of 12 counts)	834	425
1936 (average of 12 counts)	955	486
1937 (first 6 months, 6 counts)	898	480

[1] Between Moncks Corner business section and United States Highway No. 52 (formerly No. 17).

[2] Between Moncks Corner business section and Pinopolis.

mentally[1] and as routine construction. Results obtained in the use of sand-clay as a road-building material varied considerably. Because of its uncertain behavior, there were differences of opinion regarding the properties that a sand-clay should possess to be satisfactory as a base material for bituminous surfaces. These opinions were usually based upon the engineer's experience with the materials found in his particular locality. It was recognized that more definite information regarding the characteristics of sand-clay materials was essential if such a widespread and plentiful material were to be utilized to the greatest possible extent in building satisfactory low-cost roads.

MARL AND SAND-CLAY OBTAINED FROM LOCAL DEPOSITS

It was generally agreed that both the sand and the clay played important parts but it was not known what percentages of each would be most suitable or to what extent the characteristics of the component parts affected the behavior of the combination. While the methods of soil analysis now in general use had been developed at the time this experimental road was built, data sufficient for correlating laboratory tests with service behavior had not yet been obtained. Consequently, the only practical method for determining the suitability of a given material was by a service test. The same situation existed with respect to the marl.

The apparently successful results that had been obtained with limerock in base construction in Florida and Georgia led to the assumption that a somewhat similar material available in South Carolina might prove satisfactory. This material, known locally as marl, and used on 2 miles of the experimental road, was taken from a nearby deposit. Laboratory determination of the properties, which at that time were deemed the most significant, showed it to have the following characteristics:

Calcium carbonate, 84 to 87 percent.
Silica, alumina, and iron oxides, 10 to 14½ percent.
Magnesium carbonate, 1.3 to 1.7 percent.
Cementing values, 133 to 500 (plus).

The marl, when taken from the pit, was grayish white and contained some moisture. While in this condition it could be readily broken down with disks, harrows, and blade graders into a fine-grained homogeneous mass. It compacted uniformly without laminations, but developed small shrinkage cracks while drying. When dry, the surface became white, hard, and had an objectionable glare in the sunlight.

The marl base, which was 8 to 10 inches thick, was built by contract in the fall of 1928 and served as a wearing surface for traffic until August 1929. During this period its main disadvantages were its dazzling whiteness, a slight tendency to dust under steel-tired vehicles, and its tendency to soften in continued rainy weather. However, at the time the bituminous-treated surfaces were applied the base appeared to be in excellent condition.

The sand clay used in the base on 2.48 miles of the experiment was taken from a local pit and, although the best available, was not considered a good quality material largely because of its lack of uniformity and of binder. The base was built 6 to 7 inches thick and was constructed by State forces shortly before the bituminous treated surfaces were applied. Considerable work was done in manipulating the material on the road after each rain in an attempt to obtain consolidation and some degree of uniformity. Some bonding and consolidation were obtained but, at the time the experimental sections were built, the base was in only fair condition.

The bituminous surfaces were built by State forces during August, September, and October 1929. The three methods of construction used are indicated in figures 1 and 2. The details of constructing the various sections of the experiment were reported in Public Roads in November 1931, but for convenience are briefly stated in this report, the main purpose of which is to present the data and information that have been accumulated from the time of construction to June 30, 1937, together with such discussions as appear warranted.

MARL BASE BLADED AND PRIMED BEFORE CONSTRUCTING SURFACES

In maintaining the sections since their construction an effort has been made to keep them in a uniformly satisfactory condition at all times. Maintenance has consisted of patching as needed and the application of re-treatments on sections in whole or in part as required. In applying the re-treatments, the same types of bituminous material were used that had been used in the original construction. The aggregate was one-size granite that varied slightly in maximum size as shown in figures 1 and 2.

Prior to applying the tar prime, the marl base was brought to a uniform cross section by blading after sprinkling with water. The tar prime was then applied and allowed to penetrate and dry before the bituminous treated surfaces were constructed. During this drying period it was observed that the tar penetrated readily and the base hardened in areas unshaded from the sun but that where the surface was shaded, the rate and extent of penetration were less and the surface hardened more slowly.

Experiment 1, section A, stations 0+00 to 13+28.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.27 gallon of tar.
Mix: 1.8 inches thick when compacted; 154 pounds of 1¼- to ¼-inch crushed stone, 38 pounds of ¼ inch to dust, and 0.91 gallon of 60–70 cut-back.
Seal: 0.42 gallon of the same bituminous material and 30 pounds of ⅝- to ¼-inch stone chips.

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[1] Experimental Bituminous Treatment of Sandy-Soil Roads, by Paul F. Critz and H. L. Sligh. Public Roads, vol. 17, No. 11, January 1937.

It was expected that the combined fine and coarse aggregate would produce a dense mat that would not require a seal. However, the resulting mat had a coarse texture and an open surface. During a month under traffic, some raveling occurred, and it was deemed advisable to seal the surface.

Prior to applying the seal on this section, as well as on several others where the mat was very open, the surface was choked with ⅝- to ¼-inch stone and subjected to traffic for 2 days before the bituminous material and cover materials were applied.

Considering the amount of traffic carried, this section has been one of the most satisfactory of those having a marl base. During most of its life the section appeared lean, dry, and somewhat porous. The small amount of raveling that occurred was confined mostly to the edges. Cracking of the mat was characteristic of the section, and most of the maintenance required was to seal these cracks. Little trouble that could be attributed to unsatisfactory base conditions was experienced. Test holes dug through the mat and base in 1934 showed the marl base to be dry, and the mat to be well bound by bitumen below the surface, although on the surface it appeared dry and lean. French drains, installed shortly after contructing the experiment, and deep side ditches apparently furnished adequate drainage.

Only two re-treatments were applied to this section, one in 1931 and one in 1935. Both were applied primarily to eliminate the dry, lean appearance of the surface, to seal cracks, and to eliminate the nonuniformity gradually resulting from the placing of numerous skin patches used in sealing the cracks.

When inspected in October 1936, the section was in very good condition. The edges were unbroken and showed no considerable tendency to ravel although they were not well supported by shoulder material. The surface had a rather mottled appearance but it was smooth, very dense, and had a nonskid, coarse-grained texture as shown in figure 3–A. The general appearance of the section at the time of inspection is illustrated by figure 3–B, a view taken near the west end of the section.

The cost of constructing this section was 66.12 cents per square yard and the average annual cost of maintaining the surface, including base repair and the two re-treatments, has been 3.32 cents per square yard.

Experiment 1, section B, stations 13+28 to 24+50.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.27 gallon of tar.
Mix: 1.8 inches thick when compacted; 156 pounds of 1¼- to ¼-inch crushed stone, 37 pounds of ¼ inch to dust, and 1.03 gallons of 85–100 cut-back.
Seal: 0.29 gallon of the same bituminous material was applied and covered with 15 pounds of ⅝- to ¼-inch stone chips.

This was the first section constructed and was necessarily quite experimental in character as the original plan of operations did not specify many of the details of construction.

UNSATISFACTORY BEHAVIOR ATTRIBUTED TO POOR DRAINAGE

To prevent segregation of the aggregate, the coarse material was first spread and given an application of bituminous material. The finer material was then spread and the remainder of the bituminous material applied. Mixing was begun immediately with a four-way drag, somewhat lighter and smaller than those commonly used at the present time. The results obtained were unsatisfactory, so blade graders were substituted and no further difficulty was experienced. No segregation occurred that could be attributed to the grading of the aggregate.

Mixing on this section did not proceed rapidly and the partly mixed materials laid in a windrow over Sunday. During this interval some stiffening of the cut-back asphalt occurred with the result that some segregation took place during spreading of the mixture so that the center 7 or 8 feet presented a more open appearance than the remainder of the section. As with section A of this experiment, it had not been expected that this section would require a seal. However, after about 3 weeks under traffic, the larger stone began to ravel in numerous places and a seal coat was applied.

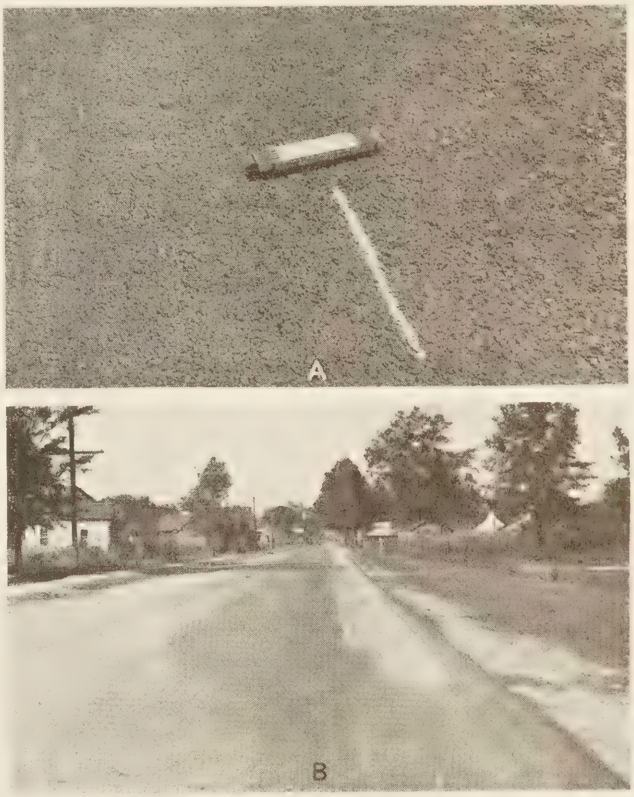

Figure 3.—Appearance of Experiment 1A in October 1936. A, Close-Up View Showing Non-Skid Surface Texture; B, General Appearance of Section. Note Even Edges, Despite Lack of Protection by Shoulders.

Although nearly identical with experiment 1A in construction and in composition, except for the penetration of the base asphalt in the cut-back, section B was decidedly less satisfactory in service. In addition to the routine maintenance required to seal cracks and to prevent raveling, considerable maintenance was required near the west end where very unfavorable drainage conditions existed. At this location the right-of-way is little wider than the treated surface, with store buildings at the right-of-way line. Natural drainage is poor and open drainage is not practical. French drains were installed but did not aid materially in lowering the water table. Attempts to stabilize the marl base by scarifying the base and surface mats and mixing them together, and also by adding coarse aggregate, were of only temporary benefit.

Figure 1 shows that the section, excepting the west portion, has received only two re-treatments, and the west portion has been re-treated four times and virtually reconstructed twice. When inspected in October 1936, the section, with the exception of the west 200 feet, closely resembled section A in appearance and condition. The west 200 feet were badly cracked as a result of the moisture conditions already described. This part of the section was re-treated later in October. By March 1937, cracks had reappeared on this area and by July the west 50 feet were badly cracked and the marl base was exposed in places.

The cost of constructing section B was 72.58 cents per square yard and the average annual cost of maintenance including base modification and re-treatments has been 5.46 cents per square yard.

Experiment 2, section A, stations 24+50 to 39+60.[2]—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.31 gallon of tar.

Mix: 2 inches thick when compacted; 180 pounds of 1¼- to ¼-inch stone and 0.69 gallon of 85–100 cut-back.

Seal: An average of 0.30 gallon of the same bituminous material was applied and covered with an average of 18 pounds of ⅝- to ¼-inch stone chips. This section was sealed in two separate portions.

MOISTURE PENETRATED BITUMINOUS MAT DESPITE SEAL COAT

It was expected that the coarse-graded aggregate used in this section would produce an open mat and that a seal would be necessary. The seal was applied after the mat had been subjected to traffic for 3 weeks. On the east half of the section the seal was constructed by first applying the bituminous material and then spreading the cover stone. On the west half, a part of the stone was spread first and keyed into the surface by traffic, after which the seal was completed as on the east half.

This section extends through the business portion of Moncks Corner for a distance of approximately 1,000 feet and consequently is subjected to more severe usage than any other section of the experimental road.

French drains were installed shortly after construction of the surface and in the spring test holes were dug to determine the moisture conditions. It was observed that the marl base was damp near the top, but was dry lower down, indicating that the moisture had percolated through the surface in spite of the seal coat.

Maintenance the first 2 years consisted mainly of skin patching to seal cracks and to prevent raveling resulting from surface wear, but by the fall of 1931 the entire section had cracked so badly as to warrant a re-treatment which was applied in November. This re-treatment apparently left the section in good condition.

Later, however, a 100-foot section near the west end began to fail. The base became soft and spongy in spite of the French drains that had been installed. The bituminous mat cracked badly and patches placed to seal the cracks and prevent disintegration of the mat repeatedly failed until it became necessary practically to reconstruct this area. In August 1932, the marl base and bituminous mat were scarified, mixed together, and relaid for compaction under traffic. In September this base was primed and a surface treatment applied.

Following this repair only a moderate amount of routine maintenance was required, primarily to seal cracks that developed on the end and central portions and that became more pronounced following freezing and thawing weather in February 1934. By the fall of 1935 the entire section, excepting about 300 feet in the center, had been skin-patched and had recracked in so many areas that a re-treatment was needed to seal all cracks, enliven the mat, eliminate worn areas, and provide a uniform appearance.

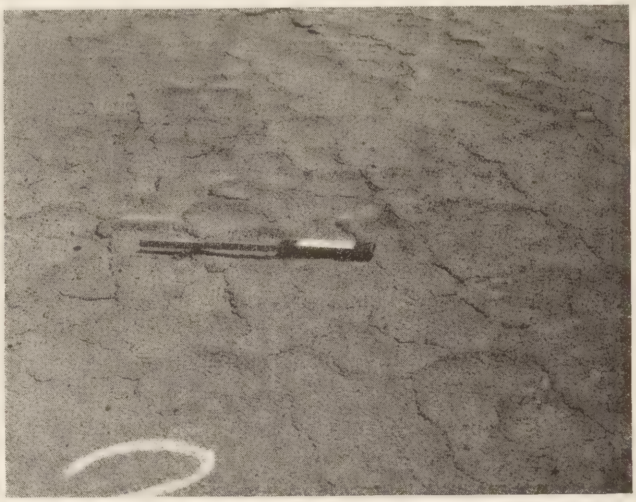
FIGURE 4.—SURFACE FAILURE ON EXPERIMENT 2A, PHOTOGRAPHED IN OCTOBER 1936.

The re-treatment was applied to the entire section in September 1935 but, after about 3 months, cracking again started and increased in amount and intensity so that another re-treatment was necessary. An inspection of the section made in October 1936, prior to applying the re-treatment, showed the section to be in poor condition. It had a number of badly broken areas of which one in the center of the business section of town was the worst. The mat in this area was not merely cracked but pieces had separated from each other and from the base. Sand had been washed into the cracks so that each piece appeared to be resting on a sand cushion. Figure 4 is an illustration of an area in this condition. Samples were taken of the marl base and of the subgrade and their analyses are given in table 1 under laboratory Nos. 10133 and 10134, respectively. The subgrade material was wet and sticky when sampled.

The portion of the section not cracked in the manner just described was in good condition. It had a smooth surface and appeared structurally sound. The re-treatment applied late in October was a heavy mixed-in-place seal. Prior to placing this treatment, 0.15 gallon of 85–100 cut-back was applied to the mat surface as a tack coat and to coat the sand particles that filled some of the cracks. The mixed-in-place mat or drag seal was composed of 0.45 gallon of cut-back asphalt with 25 pounds of ⅝- to ¼-inch stone and 25 pounds of sand per square yard. As a protective measure the treated portion of the roadway was widened 10 feet on each side through the business section of town (between stations 26+23 and 35+91). This treatment gave the section a smooth and uniform appearance and very little maintenance had been required on it up to July 1937, the end of the period of observation reported here.

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[2] The portion between stations 25+25 and 25+61 is occupied by railway tracks and was not a part of the experimental section.

The cost of constructing this section was 70.34 cents per square yard and the average annual cost of maintaining the surface has been 6.29 cents per square yard.

Experiment 2, section B, stations 39+60 to 52+00.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.29 gallon of tar.
Mix: 2 inches thick when compacted; 175 pounds of 1¼- to ¼-inch crushed stone and 0.89 gallon of 25–35 viscosity tar.
Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips.

The surface of the mat on this section, like that of experiment 2A, was porous and open. The mat, however, was well bonded and did not ravel during the 2 months it was subjected to traffic before the seal coat was applied.

CONSIDERABLE MAINTENANCE NEEDED TO SEAL CRACKS

In the spring following construction, cracked areas appeared and were skin-patched after French drains were installed below the marl base. Test holes showed the bituminous mat to be rich in bitumen and to appear well sealed although water was observed below the mat and the marl base was damp at the top. By April 1930, the mat on the west 500 feet had become wet, spongy, and so badly cracked that it disintegrated in some areas and was removed and replaced with premixed material. On the remainder of this portion the cracks were sealed. With the advent of warm weather many of the cracks that had been observed elsewhere on the section earlier sealed themselves.

The entire section was given its first re-treatment during 1931. The east 400 feet were re-treated in June to seal the excessive amount of cracks that had appeared in that area. By fall, cracking became very pronounced on the remainder of the section and, in addition, the mat on the west 200 feet began to disintegrate as a result of the spongy condition of the marl base. Four French drains were installed and disintegrated areas totaling approximately 300 square feet, were replaced with premixed material.

This work at first appeared to have eliminated an unsatisfactory condition so the section, excepting the east 400 feet, was re-treated in December. However, by the following spring this area at the west end was again in an unsatisfactory condition. Cracks appeared through the patches placed to seal them. The marl base became spongy in spite of the four French drains placed during the previous fall. Only one of the four drains showed indications of functioning. Later in the summer a 60-foot section near the west end was scarified. The marl base and bituminous mat were mixed together, laid down as a new base and allowed to dry and compact under traffic. A new mat was placed on it in September. This reconstruction eliminated the instability and spongy subgrade condition. The east 400 feet, re-treated in June, had remained in good condition.

Although cracks appeared throughout the section at times, many of them closed in warm weather and the remainder were sealed by skin-patching as they occurred. The placing of numerous patches had gradually produced a nonuniform and unsightly mat, whose surface was not very smooth. To eliminate such conditions and also to enliven the surface, the entire section was given a fairly heavy re-treatment in September 1935.

Following this re-treatment the section apparently remained stable throughout except for small cracks that appeared. Many of these closed in warm weather but some of them had to be sealed. When inspected in October 1936, the section, with the exception of the east 200 feet, appeared to be in good condition. A few small cracked areas were observed as well as some surface roughness, especially near the west end. The east 200 feet were badly cracked and this portion was given a heavy re-treatment on October 30. Following this re-treatment little maintenance was required other than that of sealing a few cracks and of spreading some additional cover stone on the east end where bleeding occurred in hot weather.

The cost of constructing this section was 79.40 cents per square yard and the average annual cost of maintaining the bituminous mat, including the base reconstruction and re-treatments, was 7.15 cents per square yard.

Experiment 2, section C, stations 52+00 to 66+00.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.28 gallon of tar.
Penetration course: 2.3 inches thick when compacted; 165 pounds of 1¼- to ¼-inch stone, 37 pounds of ¼-inch to dust, and 1.27 gallons of asphalt emulsion.
Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips.

It was planned originally to construct this section in the same manner as the two preceding sections but the producers of the emulsion objected and requested that a modified type of penetration construction be substituted. The construction which is here described therefore was done under their direction and with the approval of their representatives.

BASE FAILURE CAUSED HIGH MAINTENANCE COSTS

The screenings, ¼-inch to dust, were spread uniformly to a depth of ½ inch upon the primed marl base. The 1¼- to ¼-inch aggregate was then spread uniformly, sprinkled with water, and thoroughly rolled. Emulsion was then applied at the rate of 0.44 gallon per square yard and a strip 1 foot wide along each edge was given an additional amount of emulsion. Water was applied immediately to wash the emulsion down into the screenings and the surface was again rolled thoroughly. The second rolling was presumed to seat the coarse stone in the mortar of emulsion and screenings which would be forced up and around it. However, this expected action did not occur. Some of the water added to wash the emulsion down drained off at the edges, carrying an undetermined amount of emulsion with it. During the second rolling operation 8 pounds of ⅝- to ¼-inch stone per square yard were scattered over the surface and rolled into the surface voids. On the following day 0.83 gallon of emulsion was applied and about 7 pounds of ⅝- to ¼-inch stone per square yard were spread after which the surface was thoroughly rolled.

The seal was applied 1 week later, after the surface had been swept and loose or raveled areas had been patched. The treatment consisted of an application of 0.23 gallon of emulsion and 15 pounds of ⅝- to ¼-inch stone per square yard. Inspection showed that the first application of emulsion had not penetrated the cushion course at the bottom as expected, but, to a considerable extent, had been washed away by the water.

As shown in figure 1 and by the cost data in table 6, this section required a greater amount of maintenance than any other section and was the least satisfactory. The section lies partly in cut and partly on the highest fill on the experimental road. Trouble with moisture and failure of the marl base were experienced on this section almost from the start. First evidences of failure were surface cracks and sponginess in the base, especially near the center of the section and toward the west end where the section lies on a fill.

Surface patching was first done to seal cracks and prevent disintegration. By June 1931, however, these two areas were so badly cracked and disintegrated that the mat was scarified, remixed with additional emulsion, and relaid. A seal was then applied to these areas and also to the east 400 feet where surface cracking did not warrant remixing. In the following November, the entire section, excepting the east 400 feet, was given a re-treatment. One month later the area near the west end that had been remixed in June was given an additional re-treatment.

By September 1932, the mat on a 260-foot section near the center had become so badly cracked and the base appeared so unstable that reconstruction was deemed necessary. The marl base and the bituminous mat were scarified, mixed together, and relaid as a new base, which was then primed and covered with a heavy surface treatment. The area thus reconstructed included a portion of one of the areas whose mat had been remixed in 1931. In September 1933 the east 400 feet of the section was given its second re-treatment and two years later the remainder of the section was again re-treated. The entire section was again re-treated in October 1936.

Figure 1 shows that the entire section received three re-treatments in addition to the major surface and base repairs required on the central portion and on an area toward the west end.

FAULTY CONSTRUCTION METHODS PARTLY RESPONSIBLE FOR FAILURE

Prior to applying the re-treatment late in October of 1936, an inspection showed the east one-third of the section to be in good condition and to appear structurally sound. Approximately 350 feet adjoining it on the west were badly cracked and the mat appeared unstable. At the location examined, the mat was 3 inches thick but could be readily broken apart as it had little bond. Free water was observed in the bituminous mat and some of the aggregate had become uncoated. The area in question was on a slight grade where surface drainage was good and the location examined was but 5 feet down-grade from an intercepting lateral French drain. Samples of the marl base and of the subgrade were taken at this point and their analyses are given in table 1 under laboratory Nos. 10138 and 10139, respectively. The marl base was 7½ inches thick and while dense in appearance, was somewhat moist at the bottom. The sand-clay subgrade below the marl base was wet.

A re-treatment was applied October 30 and 31, 1936, to the entire section but by the following July the mat had cracked badly in the center of the section and had begun to ravel. Instability of the marl base again developed near the west end where it had been reconstructed in 1931. It is anticipated that this section very shortly will have to be entirely reconstructed by replacing the base or by stabilizing it in such a manner as to reduce its plastic properties.

The cost of constructing this section was 84.62 cents per square yard and the average annual maintenance cost was 13.40 cents per square yard.

The high maintenance cost of this section can be attributed in large measure to the unsatisfactory character of the marl base and the subgrade. Data shown in table 1 indicate that the base on this section possessed undesirable characteristics to a greater degree than any of the other marl base sections. The subgrade had the characteristics of soils of the A–2 plastic and A–4 very plastic groups and could be expected to be very unstable under unfavorable moisture conditions.

The method of constructing the bituminous mat, although at the time deemed satisfactory by the producers of the emulsion, would not be used at the present time. It is believed that the use of water to wash the emulsion down into the sand cushion was a mistake that was partially responsible for the excessive maintenance required, especially during the early life of this section.

Experiment 3, stations 79+20 to 92+40.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.30 gallon of tar.
Mix: 1.8 inches thick when compacted; 162 pounds of ¾- to ¼-inch stone and 38 pounds of stone ¼-inch to dust with 1.19 gallons of 85–100 cut-back.
Seal: None required.

This section was constructed in the same manner as experiments 1A and 1B, except that the coarse aggregate used was ¾ to ¼ inch in size. Approximately the same percentage of fine aggregate was used with this aggregate as had been used with the larger size stone. The resulting mat was apparently dense and well closed so that a seal was not applied.

EXPERIMENT 3 WAS BEST OF THOSE BUILT ON MARL BASE

Figure 1 and table 6 show this experiment to have been the best and the most economical to maintain, of the sections constructed on the marl base. Prior to the re-treatment in 1936 the total accumulated maintenance cost had been only 3 cents per square yard. The mat on this section, while appearing dry most of the time, remained in excellent condition up to the spring of 1936. The surface stayed smooth and unbroken. The mat remained dense and hard. No raveling occurred although a few cracks appeared, some of which closed in warm weather and the remainder of which were sealed with bituminous material.

In the spring of 1936, following a fairly severe winter, cracks in the surface appeared throughout the section. Skin-patching and sealing were not always effective in eliminating them. The section continued in this condition until October 1936, when it was given a re-treatment, the only one it received.

Prior to applying the re-treatment a fairly close examination was made of the section. It was noted that the mat was considerably cracked but that no raveling had occurred. The edges were in good condition and the surface was smooth. No base settlement was observed. Samples of the marl base and of the subgrade were taken from a cracked area near the center. At this location the bituminous mat was 2 inches thick and immediately below the surface appeared lifeless and very wet with some of the aggregate uncoated. The marl base was 7 inches thick and the core taken at this location was more moist at the bottom than at the top. The subgrade was sand-clay and it appeared more moist than the marl base.

The analyses of the marl base and of the sand-clay subgrade are given in table 1 under laboratory Nos. 10135 and 10136. Another area, approximately 300 feet west of the center, was also examined. There the bituminous mat was 2 inches thick, free from cracks, and was live and sticky. The marl base was 10 inches thick and appeared less dense than the base at the location previously examined. The subgrade was sand-clay that apparently contained little clay. The analysis of the marl base material at this location is given in table 1 under laboratory No. 10137.

The re-treatment applied the last of October 1936 was rather heavy, consisting of 0.58 gallon of 85–100 cut-back with 25 pounds of ⅝- to ¼-inch stone and 25 pounds of sand per square yard. Following this re-treatment, no maintenance was required and at the close of the observation period (July 1937) the section had a good appearance and seemed to be in excellent condition.

The cost of constructing this section was 61.07 cents per square yard and average annual cost of maintaining the bituminous surface was 2.24 cents per square yard.

Experiment 4, stations 92+40 to 105+84.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.26 gallon of tar.
Mix: 1.8 inches thick when compacted; 157 pounds of ¾- to ¼-inch stone, and 0.72 gallon of 85–100 cut-back.
Seal: An average of 0.22 gallon of the same bituminous material was applied and covered with 15 pounds of ⅝- to ¼-inch stone chips.

DENSE SURFACE OBTAINED BY APPLYING SEAL COAT

This section was similar to experiment 3 except that it contained no fine material. A dense surface was obtained by applying a seal coat instead of by mixing fine material in the mat.

This section, with two areas excepted, has been fairly satisfactory. The areas referred to were the east 400 feet and a small area near the center. Surface cracks appeared at times on all parts of the section but raveling or pot-holing was confined mostly to the two areas mentioned. Sealing with bituminous materials and warm weather eliminated most of the cracks. On the east 400 feet a re-treatment became necessary by the fall of 1931 to seal the cracks, enrich the surface, and eliminate the nonuniform appearance resulting from the patching done to repair small pot-holed areas.

Near the center, a small area became spongy and cracked badly when the marl base softened. On this area the bituminous mat was removed and the marl base was allowed to dry. A French drain was installed and a new mat of premixed material was placed. The re-treatment in 1931 and the base treatment just described constituted the major repairs required up to the early summer of 1934 when a spongy area of approximately 4 square yards developed. The marl base and mat on this area were scarified, mixed together, and relaid. After this new base had become dry and compacted, a surface of premixed material was placed.

Cracking continued in various amounts throughout the section as did a slight amount of pot-holing. Skin-patching and small premixed patches were generally satisfactory in preventing progressive failures but the numerous small patches reduced the smoothness of the surface considerably. To repair damaged areas and at the same time restore surface smoothness and uniformity, a re-treatment was applied to the entire section in September 1935. Except for the east 400 feet, this was the only re-treatment applied to this section during the period of observation. During the winter of 1935–36 no maintenance was required on the section but by the following spring some cracks appeared and some pot-holing occurred near the center of the section. This area was successfully repaired by skin-patching and by a small amount of patching with premixed material. One small area, however, repeatedly cracked where the marl base was spongy in spite of the French drain that had been installed.

Except for this small area, the section was in very good condition when inspected in October 1936. The surface was neither lean nor dry and it was smooth although somewhat mottled in appearance. The small unsatisfactory area in the center was badly cracked despite the numerous patches that had been placed. It was apparent that replacement of the marl base or stabilization by some suitable method would be necessary permanently to correct the unsatisfactory condition. The general condition of the section at the close of the period of observation was good except for the small unsatisfactory area.

The cost of constructing this section was 55.46 cents per square yard and the average annual cost of maintenance was 3.06 cents per square yard.

Experiment 5, stations 66+00 to 79+20.—The method of construction and the amounts of material per square yard used on this section were as follows:

Prime: 0.33 gallon of tar.
0.44 gallon of 85–100 cut-back was applied and covered with 50 pounds of 1¼- to ¼-inch crushed stone.

BASE MOVEMENT ATTRIBUTED TO CONSOLIDATION

Except for using a cut-back asphalt instead of the 150–200 penetration, hot-application material ordinarily used, this section was constructed by the surface-treatment method commonly used by the State at that time. Following the application of the cut-back asphalt, the 1¼- to ¼-inch cover stone was spread by hand from small stock piles previously placed at either side of the road. After the stone was spread and hand-broomed the surface was rolled. Traffic was not permitted on it for 24 hours, and during the first few days in service the stone displaced by traffic was respread and the surface was rolled intermittently.

Some patching was required on the portion of the section between stations 66+00 and 73+40 shortly after construction and this area was re-treated in November 1929. The treatment, which in reality was a seal, consisted of an application of 0.36 gallon of 85–100 cut-back and 15 pounds of ⅝- to ¼-inch stone.

During the next 2 years maintenance consisted mostly of sealing cracks and patching broken areas on the west half that had not been sealed. A seal was applied to this portion of the section in November 1931.

The east half of the section required some maintenance to seal the cracks that appeared at times. Sealing was generally effective for a considerable period but in a few instances cracks reappeared soon as a result of movement of the marl base. The base movement appeared to result from consolidation rather than from instability caused by detrimental amounts of moisture. In September 1933 cracking of the surface had become extensive on the east portion and it was re-treated. The west portion remained in good condition and was not re-treated in 1933.

The entire section required very little maintenance during the calendar years 1934 and 1935. The cracks that appeared either closed in warm weather or were sealed with bituminous material. A slight amount of raveling occurred along the edges at the west end and repairs were made by placing premixed material.

In the early months of 1936 cracks appeared throughout the section and numerous patches were required to prevent raveling. It was apparent that a re-treatment would be needed shortly. When inspected in October, before the re-treatment was applied, the section was considerably cracked but was not raveling. The surface was somewhat rough and had the typically dry, lean appearance of a bituminous surface in need of a re-treatment.

The mat and foundation were examined at station 68, approximately 200 feet from the east end. At this location the bituminous mat was 1 to 1¼ inches thick and appeared to contain water. The tar prime had penetrated ½ to ¾ inch into the marl base, which was 6½ inches thick at this point. Below the marl was a yellow sand subgrade. Directly below the bituminous mat at the point of examination free water was found at a depth of 11 to 12 inches from the road surface. On the adjacent shoulder, however, free water was found 29 inches below the surface. A sample of the marl base was taken at the location examined and its analysis is given in table 1 under laboratory No. 10140.

The re-treatment applied to the entire section later in October consisted of 0.56 gallon of 85–100 cut-back with 25 pounds of ⅝- to ¼-inch stone and 25 pounds of sand. This heavy re-treatment apparently placed the section in very good condition. Cracking and raveling were eliminated and surface smoothness was restored. It did become necessary, however, to spread small amounts of stone on the surface to prevent picking up in warm weather. Except for this richness the section was in very good condition at the close of the observation period, July 1937.

The cost of constructing this section was 28.47 cents per square yard and the average annual cost of maintenance was 5.13 cents per square yard.

PLASTIC CHARACTER OF MARL BASE CAUSED SURFACE CRACKS

In reviewing the service behavior of the sections on the marl base a number of facts appear to merit special comment. The most prevalent weakness displayed by the sections was their tendency to crack. The primary cause of cracking was the plastic character of the marl base and the fact that it was exceptionally difficult to drain even after numerous French drains had been installed. Leanness of the mixed mats and the lack of a tightly sealed surface on some of the sections permitted the entrance of moisture from the surface, thereby increasing the instability of the marl base.

Cracking also occurred on sections where there appeared to be no movement that indicated a lack of base stability. Such cracking was attributed directly to the leanness and openness of the bituminous mat.

All of the sections cracked considerably, but this characteristic was less pronounced on experiments 1A, 1B, and 3, which contained fine aggregate, than on experiments 2A, 2B, and 4, which did not contain such fine material but which were sealed in lieu of using fine aggregate in the mix. Raveling did not become especially serious at any time, as prompt maintenance prevented such failures.

Routine surface maintenance was generally effective, but where the defect lay in the base the only remedy was the removal of the base and replacement with satisfactory material.

LITTLE MAINTENANCE REQUIRED ON EXPERIMENT 6A

When the sand-clay base had been made as uniform and compact as possible under the conditions, a triangular trench was cut on each side to provide for a thickened edge for the mat. The trench was approximately 1 foot wide, and 4 inches deep on the outside edge. It was cut with a blade machine and was somewhat irregular in shape. Priming was beneficial in helping to bond the surface but during the mixing process the surface crust was considerably disturbed by construction equipment. Some of it broke up and was brought into the mix by the blade machines. Much of it was removed by hand before the mixes were placed. Under such circumstances the surface condition of the sand-clay base would obviously be quite variable when the mixed mats were completed but it was impracticable to determine the extent of such variation.

Experiment 6, section A, stations 105+84 to 119+99.—This section corresponds to experiment 1A. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.33 gallon of tar.
Mix: 2 inches thick when compacted; 171 pounds of 1¼- to ¼-inch stone, 40 pounds of ¼ inch to dust, and 1 gallon of 60–70 cut-back.
Seal: 0.34 gallon of 85–100 cut-back was applied and covered with 15 pounds of ⅝- to ¼-inch stone chips.

The appearance and early behavior of the mat obtained with the above materials was very similar to that on experiment 1A, the corresponding section on the marl base. The surface was lean and open and raveled somewhat immediately after construction. A seal treatment, although not originally planned for this section, was applied 1 month after constructing the mixed mat. The bituminous material used in the seal was an 85- to 100-penetration cut-back asphalt instead of the 60- to 70-penetration material originally intended to be used.

The fact that the maintenance cost of this section, exclusive of the cost of the 1933 re-treatment, totaled only 1.91 cents per square yard for the entire period of observation, best indicates the satisfactory service behavior of this section. Only a slight amount of maintenance was required. Shortly after construction, a few small areas had to be built up with premix material to prevent water from collecting in low spots where the sand-clay base had settled slightly. A few cracks required sealing as did a few porous surface areas.

In the fall and winter of 1932 and 1933 quite a number of cracks appeared along the edges, especially on the low side of a curve. They were sealed by skin-patching but this was of only temporary benefit as the cracks reappeared shortly. By the fall of 1933 it was apparent that a re-treatment would be beneficial in enriching the surface to eliminate the characteristically lean appearance that had gradually developed and to seal all cracks and leave the section in a uniform condition.

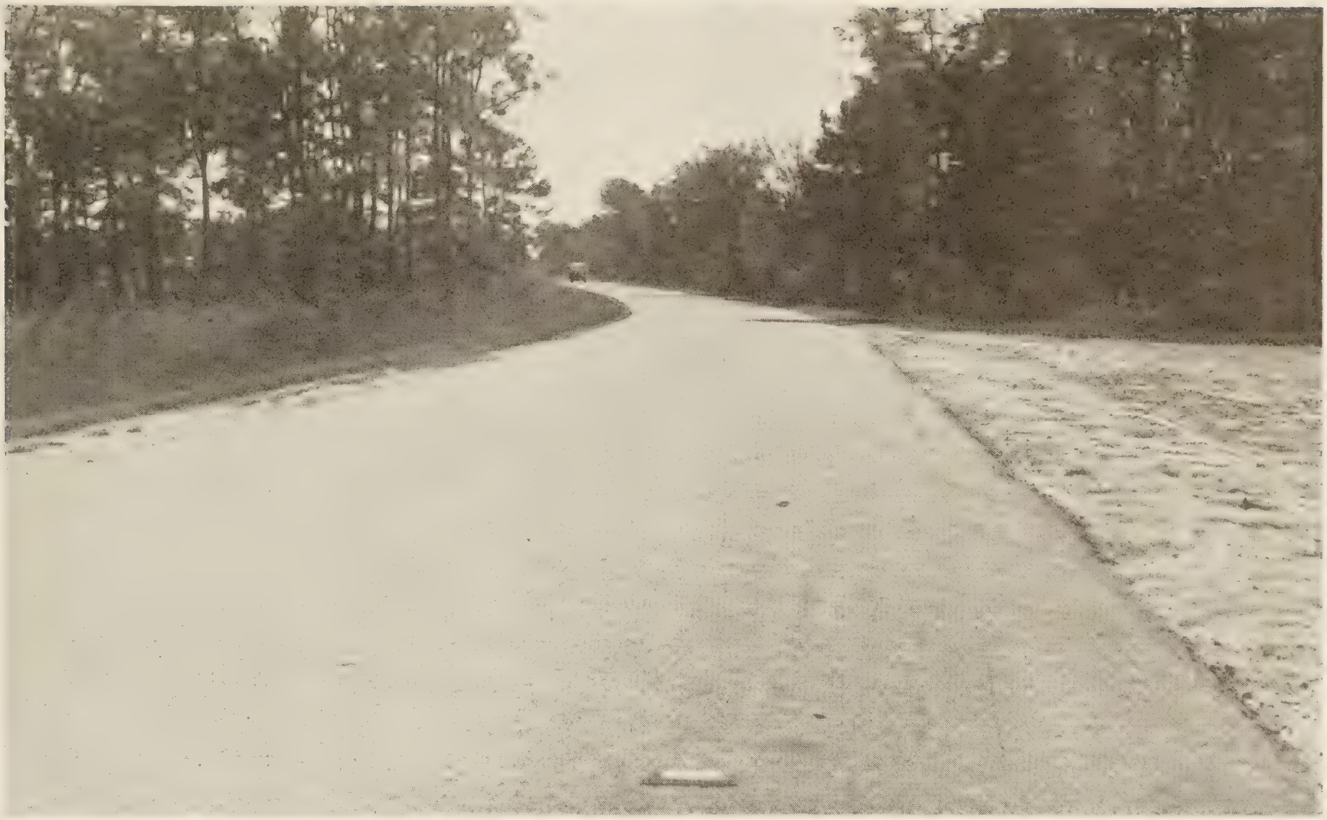

FIGURE 5.—GENERAL VIEW OF THE EAST PORTION OF EXPERIMENT 6A, WHICH IS TYPICAL OF THE ENTIRE SECTION. NOTE THE EVEN EDGES AND UNIFORM APPEARANCE.

The re-treatment was applied in September 1933, and was the only one this section received.

When inspected in October 1936, the section was in excellent condition, probably better than any other section. The surface was smooth and free from cracked or raveled areas. The edges were in very good condition and there were no ruts or other surface inequalities. Practically no maintenance had been required since the 1933 re-treatment and none was needed at the time of this inspection. Figure 5 shows a general view of the east end of the section and figure 6 shows the texture of the mat. The analysis of the section of the mat illustrated is given in table 8.

The cost of constructing this section was 72.53 cents per square yard and the average annual cost of maintenance, including the re-treatment, was 1.82 cents per square yard.

Experiment 6, section B, stations 119+99 to 132+00.—This section corresponds to experiment 1, section B. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.39 gallon of tar.
Mix: 2 inches thick when compacted; 170 pounds of 1¼- to ¼-inch crushed stone, 42 pounds of ¼ inch to dust, and 1.09 gallons 85–100 cut-back.
Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips.

Construction of the bituminous surface on this section was similar to that on experiment 1B, the corresponding section on the marl base. After the mixture had been spread but before it could be consolidated by rolling, a heavy rain fell that soaked the mix and the base. During the rolling process a number of spongy areas appeared where the sand-clay base had been softened. These areas were removed and replaced with satisfactory materials.

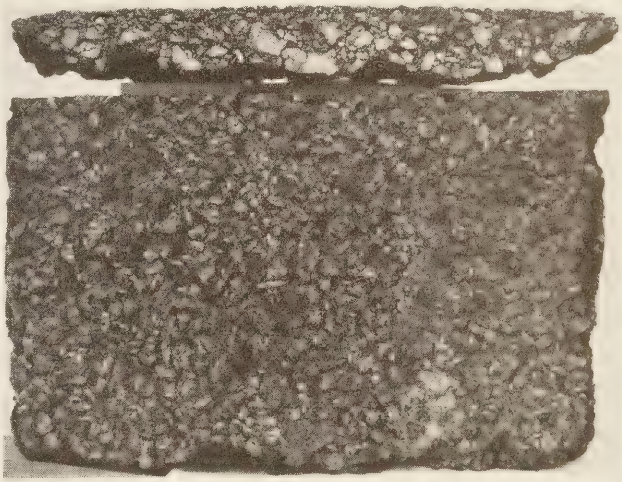

FIGURE 6.—APPEARANCE OF A SAMPLE OF THE SURFACE OF EXPERIMENT 6A IN APRIL 1937.

The seal coat was not applied until the section had been under traffic for 3 months. During this period no raveling occurred although the surface appeared lean and open.

MAINTENANCE REQUIRED BECAUSE OF BASE SETTLEMENT

The service behavior of this section has been very good as may be inferred from its maintenance cost which, exclusive of the re-treatment applied in 1931, totaled only 5.61 cents per square yard for the period of observation.

TABLE 8.—*Analyses of samples of bituminous mats, taken 7½ years after construction*

	Section 6A (station 119+76; 6½ feet right of center-line)	Section 8 (station 225+78; 4 feet left of center-line)	Section 9 (station 238+52; 5 feet left of center-line)	Section 10 (station 199+44; 5 feet right of center-line)
Composition of mat:	(1)	(2)	(2)	(3)
Bitumen ____ percent	5.6	3.6	3.7	4.7
Mechanical analysis:				
Passing 1¼, retained 1 inch ____ do	1.9	----------	----------	3.4
Passing 1, retained ¾ inch ____ do	5.8	----------	----------	6.7
Passing ¾, retained ½ inch ____ do	14.1	3.7	6.3	8.1
Passing ½, retained ¼ inch ____ do	28.5	32.0	38.3	25.0
Passing ¼, retained No. 10 ____ do	20.1	27.2	30.0	25.5
Passing No. 10, retained No. 40 ____ do	11.6	18.2	10.1	10.4
Passing No. 40, retained No. 80 ____ do	5.2	7.1	4.6	6.9
Passing No. 80, retained No. 200 ____ do	3.9	4.8	3.9	5.6
Passing No. 200 ____ do	3.3	3.4	3.1	3.7
Volatile portion of bitumen [4] ____ do	.8	.0	.4	.3
Tests on extracted bitumen recovered by the Dow method:				
Penetration at 77° F	32	35	29	27
Softening point ____ ° F	151	147	154	163
Ductility at 77° F ____ cm	14	15	8	5
Organic matter insol. in 86° B. naphtha ____ percent	32.2	29.4	32.2	34.5

[1] Represents original mat plus 1 re-treatment (1933).
[2] Represents original mat.
[3] Represents original mat plus 1 re-treatment (1931).
[4] Determined by the crank-case dilution method. A. S. T. M. D322–35.

Prior to November 1931, maintenance on this section consisted of sealing surface cracks and eliminating low areas by patching. All of this maintenance was required because of base settlement that might be more properly termed consolidation.

The only re-treatment this section received was applied in November 1931, to eliminate the nonuniform appearance that gradually developed from the routine maintenance applied and to complete in one operation all necessary maintenance. After this re-treatment was applied, the bituminous surface required only a small amount of maintenance in 1932 and none thereafter. In October 1936, 5 years after the re-treatment had been applied, the mat appeared stable and in very good condition, although it was neither as smooth nor as uniform in appearance as experiment 6A. No cracks were observed nor had raveling occurred although in the traffic lanes the surface was somewhat open and ragged in appearance where some of the cover stone used in the 1931 re-treatment had been whipped from the surface shortly after the re-treatment was applied. At the close of the period of observation, June 30, 1937, the section was in very good condition.

The cost of constructing this section was 72.10 cents per square yard and the average annual cost of maintenance, including the re-treatment, was 1.95 cents per square yard.

Experiment 7, section A, stations 132+00 to 144+20.—This section corresponds to experiment 2A. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.29 gallon of tar.
Mix: 2 inches thick when compacted; 178 pounds of 1¼- to ¼-inch stone and 0.77 gallon of 85–100 cut-back; mixed, shaped, and rolled.
Seal: 0.27 gallon of the same bituminous material was applied and covered with 18 pounds of ⅝- to ¼-inch stone chips.

Rain fell on this section about the time that the mixing operation was completed and because of the openness of the mixture, readily penetrated to the sand-clay base. Additional manipulation for drying purposes was not deemed advisable and the mixture was spread and rolled. After rolling, the surface appeared to be in good condition except for the moisture it contained. Traffic was not permitted on the surface until it had dried. The seal was applied about 1 week later after the surface had been choked with small stone under traffic. A few days after the section had been sealed the base was found to be dry and the surface apparently well sealed.

The behavior of this section was similar to that of experiment 6B except that it required somewhat more maintenance. Base settlement necessitated patching to eliminate numerous small low areas. Cracks which appeared most extensively at the west end were sealed. To reduce the routine maintenance being required and to restore surface smoothness and uniformity, the section was given its first and only re-treatment in November 1931. In the following 5¾ years, practically no maintenance was required except to patch and seal small areas where some of the cover stone used in the re-treatment had been whipped from the surface. When examined in October 1936, the section was in very good condition, The mat appeared stable and showed no evidence of impending failure. The surface was somewhat open in texture in spite of the seal and re-treatment it had received. On the east 50 feet, where equipment had turned during construction, the surface was rough.

The cost of constructing this section was 62.86 cents per square yard and the average annual cost of maintenance, including re-treatment, was 2.62 cents per square yard.

Experiment 7, section B, stations 199+70 to 212+90.—This section corresponds to experiment 2B. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.25 gallon of tar.
Mix: 2 inches thick when compacted; 169 pounds of 1¼- to ¼-inch crushed stone and 0.77 gallon of 25–35 viscosity tar.
Re-treatment: Stations 206+50 to 212+90, seal coat applied, using 0.42 gallon of the same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips. Station 199+70 to 206+50, remixed with 0.30 gallon of the same bituminous material. Sealed with 0.23 gallon of same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips.

INSUFFICIENT TAR IN ORIGINAL MIXTURE MADE SEAL COAT NECESSARY

This section was planned as a duplicate of experiment 2B on the marl base and the method of constructing the mixed mat was the same. However, the amount of tar used was about 10 percent less. This difference was sufficient to affect seriously the richness of the mixture which, when spread and rolled, immediately began to ravel under traffic; whereas on experiment 2B the mat was well bonded and did not ravel during the 2 months it was subjected to traffic before it was sealed.

Because of the lateness of the season it was thought inadvisable to remix this section with additional tar and it was decided to compensate for this deficiency by placing a fairly heavy seal coat. Tar was applied at the rate of 0.42 gallon per square yard and covered with ⅝- to ¼-inch stone chips. The supply of tar on hand was sufficient for sealing only the west 640 feet;

and by the time additional tar was received, 10 days later, the unsealed portion of the section had raveled so badly that remixing was considered necessary. Approximately 0.30 gallon of tar was added and the surface was remixed and relaid. Two months later a re-treatment, which was in effect a seal coat, was applied to this portion in order to close the surface and prevent moisture from entering.

This section has been more expensive to maintain than any of the previously discussed sections on the sand-clay base. It has, however, continued in reasonably good condition at all times. Because of leanness and gradually developing brittleness, raveling did occur on the section, mostly along the edges. Throughout the period of observation the surface was open and appeared rough but was not rough riding. Routine maintenance prevented the small amount of raveling from developing into pot holes of serious proportions and, while the section most of the time appeared to be in need of a re-treatment, none was actually applied until October 1936.

Just prior to applying the re-treatment the section was in fairly good condition. The mat was hard and brittle. Some raveling had occurred and was becoming more pronounced. Patching had been required on the west end, especially along the edges. Many parts of the section, however, were in very good condition. The surface, while dry and coarse-textured, was well bonded. Figure 7 shows the condition of such an area. It appeared that a re-treatment would be beneficial and one was applied late in October. Following this re-treatment little maintenance was required other than the spreading of small amounts of stone where the surface became somewhat soft in hot weather. At the end of the period of observation on June 30, 1937, the section was in good condition and the surface had a smooth, rich appearance.

The cost of constructing this section was 73.23 cents per square yard and the average annual cost of maintenance, including the re-treatment, was 3.47 cents per square yard.

Experiment 7, section C, stations 144+20 to 158+40.—This section corresponds to experiment 2C. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.34 gallon of tar.

Penetration course: 2.3 inches thick when compacted; 165 pounds of 1¼- to ¼-inch stone, 30 pounds of ¼-inch to dust and 1.11 gallons of asphalt emulsion.

Seal: 0.25 gallon of the same bituminous material and 15 pounds of ⅝- to ¼-inch stone chips.

This section was constructed by the penetration method without mixing. Consequently the primed sand-clay base was not disturbed in any way by the construction of the mat.

As on experiment 2C, where similar materials and methods of construction were used, a considerable amount of emulsion was carried away by the water used to wash it down into the fine stone cushion. The completed mat was rough and, during a 10-day period under traffic before sealing, it raveled considerably. Before the seal was applied raveled areas were repaired and depressions were filled with ½-inch stone and emulsion. When the section was completed it was found that here too, as on experiment 2C, the emulsion had not penetrated into the cushion course below the coarse aggregate.

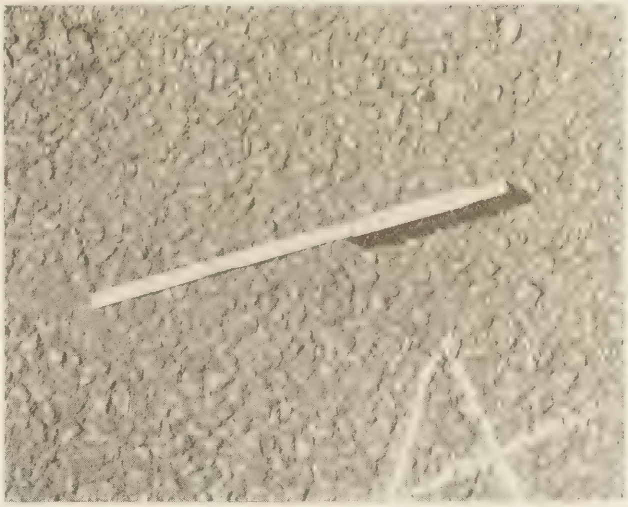

Figure 7.—Close-Up View of the Surface of Experiment 7B. Although Some Portions Raveled, Other Parts Retained a Closed, Non-Skid Surface.

Some early maintenance was required on this section to eliminate a few low areas produced by base settlement. This settlement was probably consolidation rather than movement resulting from loss of stability. Near the west end, in the vicinity of a culvert, small areas repeatedly cracked and broke where the base was somewhat spongy. French drains were installed and, when the base had dried, premixed patches were placed. This work constituted practically all of the maintenance that was made necessary by base weakness.

HIGH MAINTENANCE COST ATTRIBUTED TO METHOD OF CONSTRUCTION

To give the section a uniform appearance and to seal all cracks in a single operation, a re-treatment was applied to the entire section in November 1931. During the application of the emulsion in this re-treatment, the distributor nozzles became clogged and failed to deliver the emulsion uniformly, leaving uncoated streaks 2 to 4 inches wide and 10 to 50 feet long. Hand-pouring of emulsion on these areas did not provide a uniform cover and the amount of stone held by the treatment was consequently somewhat variable. The added emulsion benefitted the surface, however, and except for the loss of some cover stone the section remained in good condition.

Little maintenance was required after the 1931 re-treatment and consisted mainly in eliminating small pot holes resulting from the loss of stone used in the re-treatment. No further trouble was encountered with the base on the west end. Slight amounts of settlement on each side of the culvert made premixed patches necessary to maintain a reasonably smooth surface.

By the fall of 1936, the section had developed a lean, dry appearance, and its nonuniformity made a re-treatment desirable. A heavy re-treatment was applied to the entire section late in October 1936 and left the section in a uniformly good condition. In the summer following this re-treatment it became necessary to spread small amounts of stone to prevent the surface from picking up in hot weather, but no other maintenance was required. At the close of the period of observation the section was in a uniformly good condition, the surface being smooth and free from irregularities.

The cost of constructing this section was 84.55 cents per square yard and the average annual cost of maintenance, including the two re-treatments, was 5.70 cents per square yard. The maintenance cost of experiment 7C was relatively high in comparison with that of the other sections built on the sand-clay base. Unlike section 2C, its counterpart on the marl base, this relatively high cost could not be attributed, to any great extent, to the character of the base material.

The base on experiment 7C, at the time of construction, appeared very similar to that of the adjoining experiments 7A and 10 whose bases were group A-2 and A-3 materials. The high maintenance cost of experiment 7C is therefore believed to result primarily from the method of construction employed. It will be noted by reference to table 6 that the maintenance costs were relatively high up to the time of the 1931 re-treatment and were substantially lower after that time. Apparently the heavy re-treatment compensated for the lack of bituminous material resulting from the loss incurred during construction.

Experiment 8, stations 212+90 to 226+10.—This section corresponds to experiment 3. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.26 gallon of tar.
Mix: 1.8 inches thick when compacted; 154 pounds of ¾- to ¼-inch stone, 38 pounds ¼ inch to dust, and 1.25 gallons of 85–100 cut-back.
Seal: None required.

The sand-clay base on this section was very nonuniform, and under traffic compacted into strata that scaled considerably, especially along the edges. The base, when primed, had a very ragged appearance. During the mixing operation, rain fell on this section. The mixture was windrowed until the exposed base and the mixture had dried. When mixing had been completed and the mat partially rolled, local traffic rutted the surface so badly that the mat was loosened, remixed, and relaid. Although the mix had become somewhat stiff, because of loss of the volatile portion of the cut-back, no difficulty was encountered in obtaining a well-compacted and well-closed mat. A seal was not considered necessary.

EXPERIMENTS 8 AND 9 HAD LOW MAINTENANCE COSTS

The fact that the total maintenance cost of this section for 7¾ years was only 1.26 cents per square yard, and that it is still in excellent condition, indicates the continued satisfactory service behavior. The portion of the road on which this section lies is flat and has poor drainage, but the base has remained stable at all times. A few transverse cracks made their appearance after a time but no detrimental effects were observed. In the spring of 1934 an examination of the section showed the mat to be 1½ inches thick and to be sufficiently rich below the surface although the surface itself was dry and hard. The sand-clay base was dry and hard.

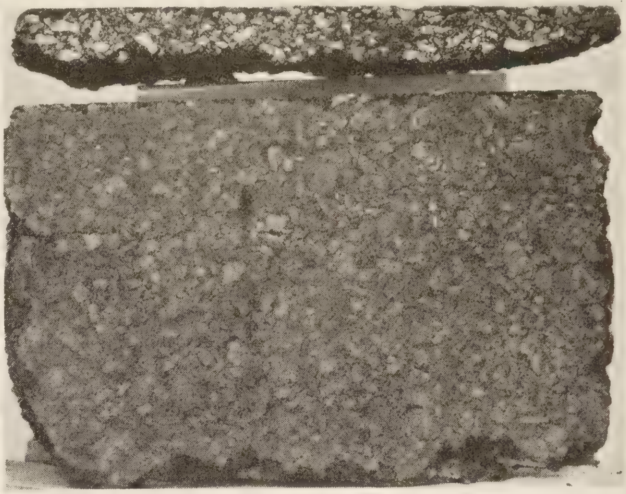

Figure 8.—Appearance of a Sample of the Surface of Experiment 8. The Cracks Shown Were Caused by Handling the Sample.

When inspected in October 1936, the section was in excellent condition. The surface was smooth and showed no defects other than the presence of a few longitudinal and transverse cracks as previously mentioned. No raveling had occurred along the cracks or on any other area of the section. Figure 8 illustrates the texture and condition of the surface and also shows a side view of the mat. The analysis of the mat at the location illustrated is given in table 8. No expenditure for maintenance was made after 1932 and, at the close of the period of observation June 30, 1937, no maintenance was needed.

The cost of constructing this section was 59.53 cents per square yard and the average annual cost of maintenance was 0.16 cent per square yard.

Experiment 9, stations 226+10 to 238+80.—This section corresponds with experiment 4. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.27 gallon of tar.
Mix: 1.8 inches thick when compacted; 152 pounds of ¾- to ¼-inch stone and 0.77 gallon 85–100 cut-back.
Seal: 0.29 gallon of the same bituminous material was applied and covered with 14 pounds of ⅝- to ¼-inch stone chips.

One month preceding construction of the bituminous surface on this section, the sand-clay base was scarified and additional clay binder added. It was then remixed, relaid, and opened to traffic for compaction. When construction of the surface was started the base was in fair condition.

The bituminous surface was the same as that on experiment 4. During the first 1½ months under traffic and before the surface was sealed, considerable raveling occurred, resulting probably from the lack of bituminous binder and of sufficient fine aggregate to provide a well-graded mixture. It had been anticipated that a seal coat would be required to obtain satisfactory surface density.

The service behavior of this section, like that of experiment 8, is best indicated by its low maintenance cost which, for the 7¾-year period, totaled only 2.92 cents per square yard. No re-treatments were applied to the section. Shortly after construction and also in the fall of 1932, some base settlement or consolidation necessitated the placing of a few patches to maintain a smooth surface. A very limited amount of skin-patching was required to seal small cracks. No transverse cracks, such as were found on experiment 8, appeared on this section. The surface throughout most of the 7¾ years appeared hard and dry but it neither pot-holed nor raveled. Practically no maintenance was required during the last 5 years of the period covered by this study.

When inspected in October 1936, the section was in excellent condition and was very similar to experiment 8 in appearance except that there were no transverse cracks. Near the edges there were light streaks, caused apparently by the failure of the end nozzles of the distributor to deliver sufficient bituminous material to hold all of the cover stone used in the seal treatment. Aside from its appearance the surface has been very satisfactory. Figure 9 shows the texture and condition of the surface. The analysis of the mat shown in figure 9 is given in table 8.

The cost of constructing this section was 66.74 cents per square yard and the average annual cost of maintenance was 0.38 cent per square yard.

Experiment 10, stations 158+40 to 199+70 (less 170 feet).—This section corresponds to experiment 5. The method of construction and the amounts of material used per square yard were as follows:

Prime: 0.29 gallon of tar.

0.46 gallon of 85–100 cut-back and 52 pounds of of 1¼- to ¼-inch crushed stone.

Re-treatment: 0.32 gallon of the same bituminous material covered with the loose stone that had been whipped off by traffic, plus 13 pounds of ¾- to ¼-inch crushed stone.

SAND-CLAY BASE GAVE GOOD SUPPORT DESPITE APPARENT LACK OF DRAINAGE

The sand-clay base on this section was very nonuniform and under traffic compacted in strata that separated when the base was swept prior to applying the prime. Some of the primed base flaked off and was removed and the untreated areas of base exposed were painted with cut-back. The cut-back and cover stone were then spread and the surface was rolled. During the rolling operation there was extensive failure of the sand-clay base. On many areas the upper portion of the base broke loose and worked up through the mat. Under traffic such areas quickly disintegrated and the surface was whipped off, leaving the base exposed. It was impractical to patch the numerous areas failing in this manner, but an immediate treatment was necessary. A treatment was applied consisting of an application of 0.32 gallon of 85–100 cut-back and a cover of approximately 38 pounds of stone, part of which was that swept from the surface before treatment and the remainder was new stone ¾ to ¼ inch in size.

Despite the difficulties encountered during construction this section has been surprisingly satisfactory and economical.

Since the bituminous surface was not constructed by the mixed-in-place method, it was expected that the irregular contour of the base would cause some surface unevenness. Such was the case and most of the maintenance applied up to November 1931 consisted of patching thin areas, filling depressions, and strengthening the edges.

The re-treatment applied in November 1931 was practically the same as the original construction except that the cover stone was ¾ to ¼ inch in size. Following this re-treatment the amount of maintenance required up to the close of the period of observation was practically negligible. When inspected in October 1936, 5 years after the re-treatment had been applied, the section was in excellent condition. The surface was smooth and dense. The edges were sound and no evidence of cracking, raveling, or other defects, was observed. Figure 10 shows the texture and surface appearance of a typical area of the section. The analysis of the bituminous mat illustrated is given in table 8.

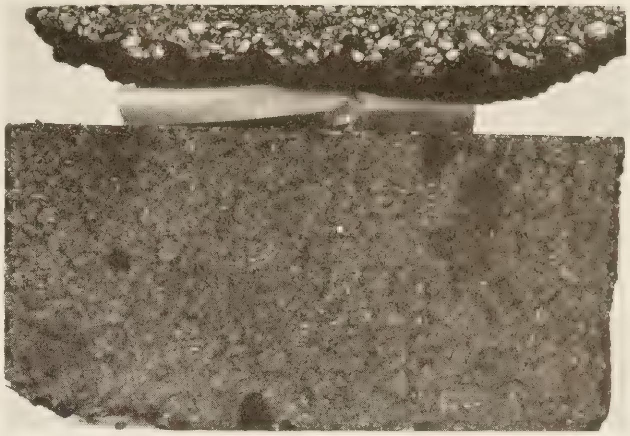
FIGURE 9.—APPEARANCE OF A SAMPLE OF THE SURFACE OF EXPERIMENT 9. THE CRACKS SHOWN WERE CAUSED BY HANDLING THE SAMPLE.

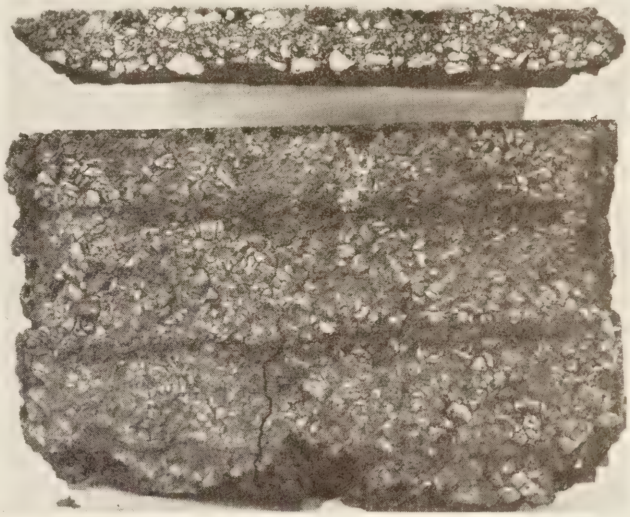
FIGURE 10.—APPEARANCE OF A SAMPLE OF THE SURFACE OF EXPERIMENT 10. THE CRACKS SHOWN WERE CAUSED BY HANDLING THE SAMPLE.

The cost of constructing this section was 29.44 cents per square yard and the average annual cost of maintenance, including the re-treatment, was 2.08 cents per square yard.

In reviewing the service behavior of the sections on the sand-clay base, probably the most outstanding fact was the excellent behavior of the sand-clay base in spite of an apparent lack of drainage since at the time of construction the sand-clay material was believed to be of inferior quality. No trouble was experienced because of moisture reaching the base and there was no reason to believe that the surfaces were more waterproof than were their counterparts on the marl base. The small amount of cracking that occurred on the sand-clay sections appeared to be caused in practically all instances by base settlement and compaction rather than by softening and loss of supporting power. Repeated maintenance of a given area was required only on experiment 7C, where the subgrade was unstable. Even at this location when the base was exposed and allowed to dry it acquired adequate stability and remained stable thereafter.

At the close of the period of observation, all of the sections were in good condition and gave every indication of long continued good behavior.

INFORMATION OBTAINED ALREADY PUT TO PRACTICAL USE

As stated in the original construction report and earlier in this report, the purpose of this experiment was to obtain information on a number of subjects of considerable importance in low-cost bituminous road construction among which were:

1. Information on the suitability of a local marl and a local sand-clay as base materials for bituminous surfaces.
2. The comparative value of various types of liquid bituminous materials.
3. The relative merits of variously graded aggregates.
4. The comparison of bituminous wearing surfaces produced by different methods of construction.

Since this experimental road was built, many hundreds of miles of bituminous surfaces have been built. All of the materials used in this road and most of the methods used are still employed in constructing bituminous surfaces. The successful results that are being obtained at the present time are based upon experience gained on previous construction as well as on the more carefully controlled and observed experimental section such as herein decribed.

Obviously the application of results obtained from experimental sections of this character must of necessity take place in advance of the time of publishing a report that covers a service behavior record for any extended period of time. For this reason most of the information developed by this experiment has already been put to practical use. However, the fact that the work has been closely observed and cost records carefully kept for 8 years and that it is still in service makes it of interest.

Discussion must obviously be confined to the experimental sections and any conclusions drawn or assumptions made would not necessarily be applicable to other sections that might, upon superficial examination, appear to be the same but which, in reality, might be widely different.

The fact that one of the subjects upon which information was sought in this experiment was the use of marl and sand-clay as base materials indicated the realization of the importance of bases for flexible pavements. As previously mentioned, the varied degrees of success that had been obtained with sand-clay were almost as numerous as were the various possible combinations of it. Little knowledge of the characteristics that affected its road-building properties was available and the only method of determining its suitability was by the relatively costly method of constructing an experimental road. Marl was used because it was available locally and because of its successful use in neighboring States. At the time the bituminous wearing surfaces were constructed the marl base appeared to be in excellent condition. Its surface was hard and smooth and apparently was not affected by occasional rains. Its behavior as an untreated surface gave no indication of the properties that were to result later in unsatisfactory behavior.

The sand-clay base, on the other hand, appeared to be in only fair condition when the bituminous treatments were applied. In spite of the blading, mixing, and shaping that was done on numerous occasions, it appeared impossible to obtain a uniform, well-compacted base that would remain undisturbed by traffic until it was protected by the bituminous wearing surface. Here, too, the properties that were to affect its service behavior were not recognized, solely because of the fact that soil-study methods had not reached their present stage of development. Table 1, which gives the properties of the soil comprising the sand-clay, the marl, and the sub-base under the marl, shows that those properties of the sand-clay that made it rather difficult to place and compact were very desirable characteristics so far as concerns the influence of moisture upon it; and that instead of being an inferior base material it was, except for lack of uniformity, an excellent one generally and its service behavior could have been anticipated had its characteristics been better understood.

MOISTURE BENEFITED SAND-CLAY BASES, HARMED MARL BASES

It will be observed that the sand-clay as represented by 19 tests had the characteristics of soil groups A–1, A–2, and A–3, and that in only one instance was it shown to have plastic properties sufficient to indicate possible unsatisfactory behavior in the presence of moisture. The marl, as represented by six tests, is shown to possess the characteristics of soils of the A–2 plastic, A–4, and A–5 groups, and consequently was adversely affected by moisture. In addition, group 5 soils possess undesirable elastic properties.

During the periods in which the marl and the sand-clay served as wearing surfaces the marl was decidedly more satisfactory than the sand-clay, but after the bituminous surfaces had been placed and the moisture content had increased there was an immediate reversal of behavior. The sand-clay base was benefited by the increase in moisture while the marl was detrimentally affected. Further reference to the analysis of the material underlying the marl shows that this material, in four out of seven instances, could have been expected to serve more satisfactorily as base material than the marl itself and in only one instance, judged by its analysis, would it have been expected to be much less satisfactory.

The better behavior of the bases of experiments 3 and 4 might be expected to have resulted from the better sub-base under the marl and the satisfactory behavior of the bases of experiments 1A and 1B might be expected to have resulted from the construction of the deep side ditches that apparently were of considerable benefit to the plastic and feebly plastic A–2 soil sub-base. The side drainage on the sand-clay base sections was not as ample as that on the marl base, and experiments 8 and 9 especially had practically no drainage. The characteristics of the soil composing the sand-clay indicated that drainage was not so vitally important and its service record substantiates the prediction that soils of this character would be stable even under rather unsatisfactory moisture conditions. It appears to have been definitely demonstrated by this experiment, therefore, that local designations for soils or chemical analyses of them alone are of little value in anticipating probable service behavior. The present method of determining the grading and physical properties of soils seems, in general, to provide the most reliable information thus far developed upon which probable service behavior can be predicted with reasonable accuracy.

This is further confirmed by the results of a study [3] conducted later by the Bureau of Public Roads on

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[3] Road-Building Limerocks, by R. C. Thoreen, PUBLIC ROADS, Vol. 16, No. 8, October 1935.

Table 9.—*Analyses of limerocks or marls used in base construction in Alabama, Florida, and Georgia and on the experimental sections*

	Identification and service behavior									
	Group 1,[1] excellent		Group 2,[1] good		Group 3,[1] fair		Group 4,[1] poor		Experimental sections[2] mostly poor	
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Chemical composition:										
Silica, alumina, and iron oxide..percent..	0.78	0.40- 1.35	7.82	3.5 - 11.1	1.67	0.35- 3.20	8.29	6.65- 10.0	----------	10.4 - 14.6
Calcium carbonate.....do....	98.3	97.8 -98.7	91.1	87.5 - 96.1	97.1	95.3 - 98.8	89.7	87.7 - 91.6	----------	83.9 - 86.9
Magnesium carbonate.....do....	.80	.76- .87	.74	.61- .87	.96	.76- 1.51	.93	.68- 1.44	----------	1.33- 1.65
Soil test constants:										
Liquid limit	21	17 -26	20	18 - 23	24	20 - 27	28	23 - 34	38	36 - 41
Plasticity index	0	0	4	0 - 6	4	0 - 7	11	8 - 17	9	5 - 17
Shrinkage limit	25	21 -35	20	16 - 25	25	22 - 29	21	16 - 24	30	27 - 32
Shrinkage ratio	1.6	1.4 - 1.7	1.7	1.6 - 1.8	1.6	1.5 - 1.7	1.7	1.6 - 1.8	1.4	1.4 - 1.5
Centrifuge moisture equivalent	17	14 -23	16	12 - 20	23	19 - 30	25	18 - 31	23	19 - 29
Field moisture equivalent	19	16 -24	19	15 - 22	24	21 - 30	21	17 - 24	34	29 - 42
Other physical tests:										
Cementing value	20	11 -53	83	50 -110	57	11 -168	180	67 -387	----------	133 -500+

[1] From Road-Building Limerocks, by R. C. Thoreen, PUBLIC ROADS, October 1935.

[2] From table 1.

road-building limerocks, which include marls. This study was made to correlate test analyses with service behavior. The materials studied were those actually used in base construction in Florida, Georgia, and Alabama. The test results are summarized in table 9 and are grouped according to the service behavior of the materials studied. For convenience of comparison, the analyses of the marl on the experimental sections are also included in this table.

NO FAILURES COULD BE ATTRIBUTED TO IMPROPER GRADING

The differences in the characteristics of the bituminous materials used on these sections were not reflected in their service behavior. The weaknesses that developed in the bituminous mats resulted primarily from unsatisfactory base conditions and the use of a relatively low percentage of bituminous material rather than from the type of bituminous material used. All of the mats were relatively lean and as a result were too rigid to adjust themselves to any appreciable base movement without cracking.

Moisture also had a deterimental effect on the lean mixtures. Had a greater amount of bituminous matetial been used it is very probable that the amount of cracking would have been greatly reduced. Raveling may follow cracking or may occur independently of it when the percentage of bituminous material is low or when the bituminous residue has hardened as a result of weathering. However, on this project, raveling was not extensive because of the prompt and continued maintenance. On experiment 7B, the tar section on the sand-clay base, a small amount of raveling occurred although it was not extensive enough to warrant a re-treatment until 1936. On experiment 2B, the corresponding section on the marl base, raveling was more pronounced. On this section the base movement and moisture caused a considerable amount of cracking that resulted in raveling in spite of maintenance.

No difference in behavior was observed that could be attributed to the penetration of the base asphalts used in the cut-back materials. The nonuniform appearance of experiment 7C, in which an emulsion was used, resulted from the mechanical difficulty encountered in applying the emulsion with the equipment available rather than from the character of the emulsion.

The viscosities of the materials used in mixing and in the seal and surface treatments were relatively low in comparison with those now generally considered suitable for these purposes. The initial viscosity greatly influences the amount of bituminous material that will be retained by the aggregate, and it is problematical whether additional bituminous material of as low viscosity as that originally used with the relatively open stone mixes would have produced a less rigid mat. It is probable that increasing the percentage of bituminous material would have resulted in a nonuniform mat with the bottom portion being excessively rich, unless the bituminous material was added in increments with manipulation and drying periods following each application. With such a procedure, however, there is considerable likelihood that excessive segregation of particles would occur.

The use of a higher viscosity material and a greater percentage of it might have provided a bituminous mat that would have been less susceptible to cracking or to raveling and that would have been more resistant to the effect of moisture. This would have been particularly beneficial for the sections constructed on the marl base. The service record and maintenance costs of the sections on the sand-clay base indicate that their design was satisfactory for the existing conditions.

One of the purposes of the experiment was to obtain information on the effect of the size and grading of the aggregate. Information was desired on the value of relatively dense-graded aggregate as compared with a more open grading and also upon the merits of various maximum-size aggregates. As shown in the report, aggregates graded from 1¼ to ¼ inch and from ¾ to ¼ inch were used with and without finer material added. It was expected that where material from ¼ inch to dust was used in the mix the mat would be sufficiently dense as not to require a seal but that where such material was not used a seal would be required.

Approximately 20 percent of material from ¼ inch to dust was used with both the 1¼ to ¼ inch and the ¾- to ¼-inch aggregates. It was observed during construction that the resulting mixtures were harsh and apparently would have been benefited had the percentage of finer material been increased. This was especially noticeable where the maximum-size aggregate was 1¼ inches. Because wide differences of opinion still exist regarding the grading of aggregates and successful performance has been obtained with a wide variety of gradings, it could hardly be said that better results would have been obtained had the gradings been changed, especially since the service behavior gave no indication of failures resulting from improper grading.

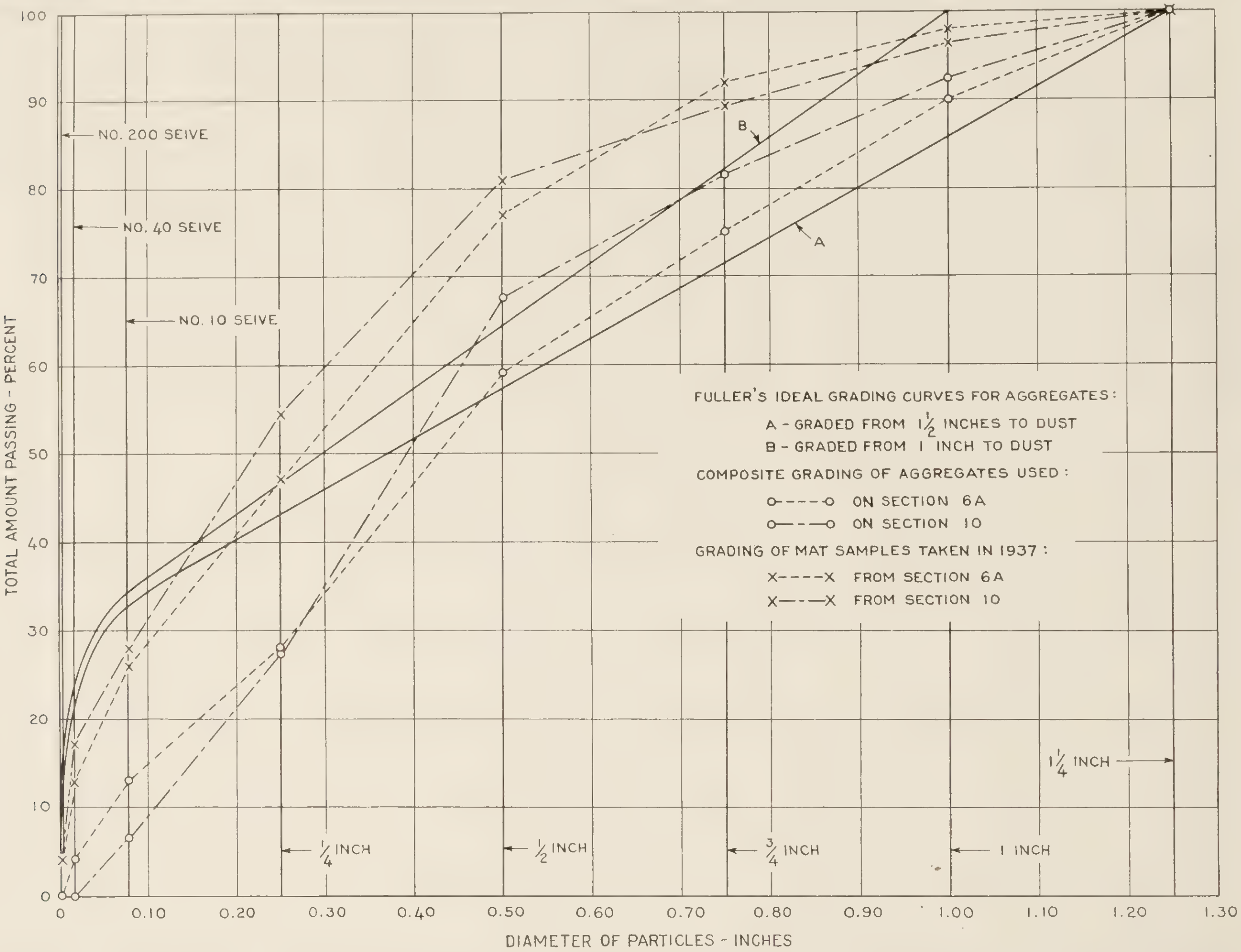

Figure 11.—Comparison of Original and Final Gradings of Aggregates Used in Experiments 6A and 10 With Fuller's Ideal Curve for Maximum Practical Density.

AGGREGATE GRADINGS COMPARED WITH FULLER'S CURVES

If it is assumed that a grading conforming substantially to that sometimes referred to as Fuller's Ideal Grading Curve for Maximum Practical Density [4] can be satisfactorily used as a basis of comparison, interesting information is developed by a study of the aggregates used and of the changes in grading that occurred in service. This discussion is limited to a consideration of those sections, the ultimate grading of whose aggregates was determined by extraction and mechanical analysis after 8 years of service. For convenience the gradings are plotted in figures 11 and 12. The original gradings are based upon the percentages and gradings of the aggregates used, and the final grading is the mechanical analysis of the aggregate extracted from mat samples taken in 1937. In the sample taken from experiment 6A the aggregate is the composite of the coarse and fine material in the mix and the ⅝- to ¼-inch aggregates used in the seal and in the 1933 re-treatment. Experiments 8 and 9 were not re-treated, consequently only the aggregate placed at the time of construction is involved.

The use of approximately 20 percent of the finer material, graded from ¼ inch to dust with the 1¼ to ¼-inch aggregate in experiments 1 and 6, produced a mixture that was apparently not dense enough to permit omitting the seal treatment. It was originally reported that "at least 30 percent of fines would have been necessary in order to produce a surface (density) similar to that obtained with (aggregate graded from) ¾ inch to dust." Considering the portion retained on the ¼-inch sieve as coarse and that passing it as fine material, it will be observed from the grading curve for experiment 6A in figure 11 that actually 28 percent of fine material was present although according to Fuller's curve A, 40 to 45 percent could have been used. Had 30 percent of the material graded from ¼ inch to dust been used as suggested in the original report, the resulting grading would have been in substantial agreement with that given by Fuller's curve.

The final grading of the aggregate as determined by an extraction test on a sample taken from experiment 6A in 1937 is shown in figure 11. As will be noted, the percentage passing any given sieve has greatly increased indicating that a considerable amount of crushing has occurred. Since practically all of the extracted aggregate passed the 1-inch sieve, Fuller's curve B, for 1-inch maximum-size aggregate, is more applicable for comparison. Therefore using curve B as a basis for comparison, it will be noted that as a result of the crushing that occurred the final grading has more nearly ap-

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[4] Concrete Plain and Reinforced, by F. W. Taylor, S. E. Thompson, and E. Smulski. John Wiley & Sons, New York.

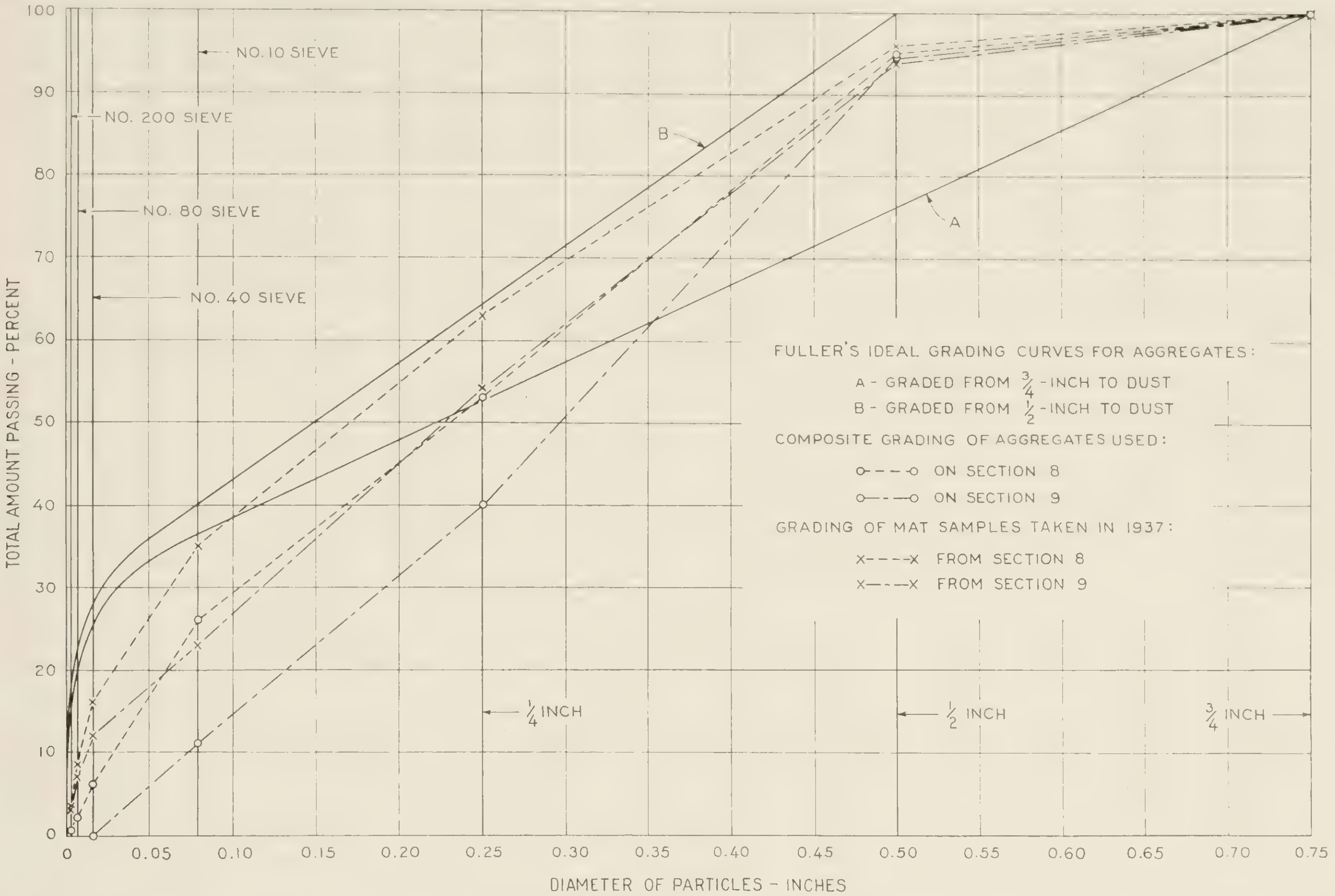

Figure 12.—Comparison of Original and Final Grading of Aggregates Used in Experiments 8 and 9 With Fuller's Ideal Curve for Maximum Practical Density.

proached the maximum density curve especially for the ¼-inch and smaller sizes.

On experiments 3 and 8, where approximately 20 percent of the finer material was used with ¾- to ¼-inch stone, the mixture was not harsh and the resulting mat seemed sufficiently dense as not to require a seal. It appeared that the amount of finer material used with the smaller-sized coarse stone was much more nearly correct than that used with the 1¼- to ¼-inch stone and the grading curves in figure 12 verify this.

FINDINGS RELATIVE TO CHANGES IN GRADING SUMMARIZED

Although 20 percent of fine material was added to both the ¾- to ¼-inch and the 1¼- to ¼-inch stone, the grading of the ¾ inch to dust material actually contained approximately twice as much material passing the ¼-inch and No. 10 sieves as did the combined material graded from 1¼ inches to dust. However, since the smaller maximum-size material requires increased amounts of finer sizes for a given density and because the ¾ inch to dust material was in effect ½ inch to dust originally, it is apparent by reference to curve B in figure 12 that the percentages of material passing the ¼-inch and No. 10 sieves should have been 64 and 40, respectively, instead of 53 and 26 percent, the combination actually contained. Moreover, it is interesting to note that as a result of the crushing that later occurred, the final material actually contained 63 percent passing the ¼-inch sieve and 35 percent passing the No. 10 sieve.

Grading curves for the aggregate used and of that extracted from the mat in 1937 from experiment 9 also are shown in figure 12. On this section the ¾- to ¼-inch stone in the mixed mat contained no fine material, as surface density was to have been obtained by the seal treatment in which ⅝- to ¼-inch stone chips were used. It would not be expected that the original grading would conform to Fuller's curve and it will be noted that it was practically a straight-line grading from ½-inch to the No. 40 sieve. Its final grading, however, is very similar to Fuller's curve in form although it is deficient in all sizes smaller than ½ inch. The difference between the original and final gradings, which is a measure of the crushing that occurred, is greater on experiment 9 than on experiment 8. The increases in percentages passing the ¼-inch, No. 10 and No. 40 sieves are 14, 12, and 12, respectively, for experiment 9 while the corresponding percentages for experiment 8 are 10, 9, and 10. Some such difference might be expected in view of the fact that the graded mixture in experiment 8 was denser initially and therefore less susceptible to crushing.

Corresponding curves for the aggregates used on and extracted from the surface of experiment 10, which was a surface-treated section, are shown in figure 11. The aggregate used originally contained approximately the same percentage of material passing the ¼-inch sieve as did the combined aggregate of experiment 6A but substantially lesser amounts of material passing the No. 10 and No. 40 sieves. After 8 years in service, however, the percentages passing the ¼-inch, No. 10

and No. 40 sieves had increased to 54, 28, and 17 percent, respectively, as compared with the corresponding sizes of the material in experiment 6A which were 47, 26, and 13, respectively. Here also, as on experiment 9, considerably more crushing occurred than on the section where the mat was more dense originally.

Summarizing the findings relative to the changes in grading that occurred, the following facts appear to have been established:

1. Regardless of maximum size of stone used, crushing was more pronounced on the open type of mat than where greater density was provided initially.
2. On both open and closed types of mats, crushing was less where the smaller maximum-size aggregate was used.
3. For all gradings and on both open and closed types, crushing tended to produce increased density and the resulting grading approached that of Fuller's curve for maximum practical density.

Visual examination of the mat samples taken after 8 years in service showed them to be quite similar in appearance. All of them were hard and dense and well bonded despite the fact that the surface area of the aggregate had increased greatly because of the crushing that had occurred. The mats were so similar in appearance as to make detection of the method of construction used impossible.

Considering the character of the mats and the final gradings attained, it appears that the size and grading of the friable granite aggregate used on this project was of no great importance. It might even be inferred that crushing not only was not detrimental but was beneficial in providing greater density and stability than could have been obtained otherwise. As crushing occurred there was a corresponding increase in density and a reduction in voids. The low percentage of bituminous material used evidently became sufficient as the particles were brought into closer contact under the action of traffic. Had crushing not occurred it is quite likely that raveling would have been more pronounced.

With an aggregate so susceptible to crushing, it is quite possible that if a greater percentage of bituminous material had been used originally the mats might eventually have become too rich when greater density was obtained. This may explain the frequently observed tendency of bituminous mats to develop rich or fat spots after a considerable period of satisfactory behavior.

The road-mix and inverted penetration methods used on this work are in common use at the present time and are proving very satisfactory where the materials used have been properly selected. Direct penetration methods are also being used satisfactorily but the particular penetration method used in constructing experiments 2C and 7C would not now be considered good practice. Some unsatisfactory areas developed on sections constructed by each of the three methods but factors other than the construction method used were responsible for their unsatisfactory behavior, except that, as previously noted, the penetration method used on experiments 2C and 7C is believed to be at least partially responsible for their behavior.

CONSTRUCTION AND MAINTENANCE COSTS GIVEN FOR EACH SECTION

For the road-mix type of construction, densely graded aggregates, especially those containing appreciable amounts of material passing the number 200 sieve, are not generally used with rapid-curing materials. On this experimental road no difficulty was encountered in obtaining mixtures of uniformly coated aggregate either with the 1¼ inches to dust aggregate or with that graded from ¾ inch to dust. Although the air temperatures were relatively high, the loss of the volatile portion of the bituminous material was not sufficient to interfere with the manipulation and placing of the mixtures. The character of the distillate used in the cut-backs was such as to provide a material more nearly resembling the medium-curing type of cut-back; consequently, it is likely that a greater amount of fines could have been used without greatly increasing the work of mixing.

For a number of years the inverted penetration or surface-treatment method has been used satisfactorily on many miles of construction where a relatively thin mat was deemed adequate. Its low initial cost, ease of maintenance, and the fact that it serves excellently in stage construction show its economy and adaptability. Reference to the views of experiment 10 in figure 10, and to its analysis in table 8, show that the seal and re-treatment, together with the crushing of the aggregate that occurred in service, eventually produced a mat that was very similar to those originally obtained by the road-mix method. Although the liquid bituminous material was satisfactory in the surface-treated sections of this road, the use of a more viscous material is more generally favored in constructing surface-treated roads. Such material offers better protection against moisture, and, as it becomes very viscous almost immediately upon application, the cover stone is readily held in place.

For convenience of comparison, a summary of the cost data is given in table 10. It will be observed that little relation exists between the costs of construction and of maintenance. All of the sections on the sand-clay base were more economical to maintain than were the corresponding sections built on the marl base. Moreover, it is interesting to note that, in the order of their cost of maintenance, the corresponding sections on the two bases are almost identical, which fact might indicate that the character of the base was not the sole cause of the difference but that the type of structure had some effect on the maintenance cost.

Experiment 10 has been the most economical in total cost in spite of its annual maintenance cost of 2.08 cents. Experiments 6A, 6B, 8, and 9 have been more economical to maintain but their total costs are greater than that of experiment 10. The difference in maintenance cost between experiments 8 and 10 is sufficient to make experiment 8 the more economical after a period of 8 years providing, of course, that future maintenance costs continue in the same proportion as in the past. No other section would approach experiment 10 in economy within any reasonable period of time.

Based on their behavior, it is reasonable to expect that the sections on the sand-clay base will continue to give satisfactory service with little increase in maintenance cost under the conditions now existing. Moreover, the present structural soundness of the base and mat are apparently such that improvements to meet increased traffic demands could probably be made without sacrificing the present investment.

The same situation does not exist for the sections on the marl base, with the exception possibly of experiments 1A, part of 1B, 3, and 4 where good drainage exists. It is improbable that the marl bases on this road will ever be better than in the past, and there is little reason to expect that any bituminous surface placed on it will be satisfactory for any considerable period. Stabilization of the marl base to reduce its adverse reaction to moisture would be necessary in order to provide a foundation comparable with that provided at present by the sand-clay material.

TABLE 10.—*Summary of cost data*

SECTIONS ON MARL BASE

Section	Costs in cents per square yard				Order of maintenance cost
	Construction	Maintenance	Total to July 1, 1937	Average annual maintenance	
1A	66.12	25.75	91.87	3.32	6
1B	72.58	42.29	114.87	5.46	4
2A	70.34	48.73	119.07	6.29	3
2B	79.40	55.42	134.82	7.15	2
2C	84.62	103.86	188.48	13.40	1
3	61.07	17.39	78.46	2.24	8
4	55.46	23.69	79.15	3.06	7
5	28.47	39.77	68.24	5.13	5
Average	64.77			5.81	

SECTIONS ON SAND-CLAY BASE

Section	Construction	Maintenance	Total to July 1, 1937	Average annual maintenance	Order of maintenance cost
6A	72.53	14.11	86.64	1.82	6
6B	72.10	15.12	87.22	1.95	5
7A	62.86	20.29	83.15	2.62	3
7B	73.23	26.91	100.14	3.47	2
7C	84.55	44.19	128.74	5.70	1
8	59.53	1.26	60.79	.16	8
9	66.74	2.92	69.66	.38	7
10	29.44	16.14	45.58	2.08	4
Average	58.10			2.28	

CONCLUSIONS

The record obtained and the observations made on this road during the period covered by this report appear to warrant the following conclusions:

1. The service behavior of the bituminous surfaces was affected more by the character of the base than by the types of surfaces or the materials used in them.
2. The suitability of marl and of sand-clay as base materials was not indicated by their apparent similarity to other like materials or by their behavior before the bituminous surfaces were applied.
3. Definite knowledge of the characteristics that affect the service behavior of soils would have made possible the use of local materials to the best advantage and would have eliminated the likelihood of importing material that was inferior to that already at hand.
4. The present method of soil analysis and classification provides reliable information on the characteristics of soils and on their probable service behavior under given conditions.
5. Satisfactory bituminous surfaces can be constructed by various methods but the materials used should be suited to the method selected.
6. In the design of mixtures, consideration should be given to the possibility of the aggregate crushing under traffic, in order that the increase in density will not result in the voids being over-filled with bituminous material.
7. The construction of an adequate base will greatly reduce maintenance costs and will make possible the construction of a relatively thin and economical surface.
8. The construction of a thin mat that is satisfactory for current needs is most economical, providing adequate base support is provided originally, and such a surface can be strengthened to meet increased traffic demands.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MARCH 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 6,865,382	$ 3,146,870	239.5	$ 7,605,982	$ 3,792,846	278.1	$ 915,180	$ 454,285	35.6	$ 3,430,460
Arizona	2,046,022	1,533,122	109.0	1,477,764	1,029,914	57.9	208,563	147,876	8.1	2,018,055
Arkansas	1,150,199	1,135,954	81.3	3,699,891	3,695,817	231.5	296,465	293,960	15.8	1,868,439
California	9,837,151	5,364,140	230.3	5,253,068	2,829,772	77.9	1,371,105	729,650	13.6	4,736,621
Colorado	2,565,088	1,368,707	99.3	2,734,853	1,456,727	85.0	1,531,850	851,780	31.5	2,862,326
Connecticut	934,030	455,835	8.9	684,518	337,455	7.9	470,630	233,815	5.7	1,915,211
Delaware	485,437	241,521	14.1	708,131	349,289	9.9	393,608	188,365	6.6	1,562,442
Florida	2,648,707	1,323,880	59.5	2,935,786	1,467,893	58.5	282,400	141,200	6.3	3,781,841
Georgia	5,142,252	2,472,651	254.8	5,005,390	2,502,695	254.1	1,705,150	852,585	98.9	7,076,705
Idaho	2,099,436	1,208,877	200.7	1,189,538	710,407	38.9	714,215	432,431	18.2	1,916,121
Illinois	11,503,316	5,703,172	307.3	7,550,526	3,771,709	164.3	3,142,509	1,571,209	77.4	4,698,237
Indiana	6,098,345	2,989,340	159.6	3,430,014	1,715,007	66.3	2,645,753	1,218,953	52.6	3,644,710
Iowa	7,846,834	3,664,762	263.5	4,426,917	1,826,033	141.5	504,669	147,600	34.5	2,635,539
Kansas	5,167,966	2,571,924	724.7	4,062,913	2,031,456	175.7	4,054,918	2,019,754	215.1	4,253,088
Kentucky	5,585,639	2,771,091	209.3	2,743,030	1,371,515	59.0	2,010,982	1,005,689	51.1	3,442,176
Louisiana	1,446,064	718,483	38.2	10,983,479	2,576,110	31.7	1,415,560	614,921	27.1	3,258,300
Maine	2,794,504	1,356,812	65.5	1,710,959	854,059	33.0	126,180	63,090	3.2	1,009,282
Maryland	1,085,456	542,728	17.1	2,467,978	1,222,851	40.7	822,470	397,000	11.2	2,338,785
Massachusetts	1,874,284	937,139	9.0	3,092,767	1,545,740	20.3	1,122,427	557,100	14.6	3,280,162
Michigan	7,875,485	3,752,043	166.1	4,200,328	2,099,512	120.6	1,397,095	688,621	32.2	3,689,518
Minnesota	4,862,727	2,351,927	301.6	5,854,665	2,904,563	267.4	1,137,912	568,051	61.2	4,697,786
Mississippi	4,966,478	2,079,413	210.8	7,963,242	3,027,236	355.3	1,486,800	594,000	43.6	3,289,271
Missouri	5,727,680	2,728,407	151.9	3,006,954	1,474,486	73.5	4,612,543	2,214,880	194.4	4,964,270
Montana	1,653,927	929,612	83.6	1,127,372	633,780	30.3	2,074,909	1,165,039	117.6	5,147,491
Nebraska	3,804,397	1,837,691	339.5	5,511,115	2,778,101	433.4	3,259,156	1,627,525	345.1	2,986,487
Nevada	1,407,318	1,180,891	168.8	1,728,043	1,491,468	61.0	127,111	109,181	2.6	1,601,772
New Hampshire	964,683	473,138	22.4	382,110	190,095	3.3	143,338	71,637	4.9	1,627,195
New Jersey	2,637,665	1,309,420	18.3	2,904,016	1,449,453	26.4	367,180	183,590	2.4	2,859,493
New Mexico	2,274,475	1,481,769	242.6	1,861,935	1,135,415	84.9	390,381	237,250	13.8	1,772,011
New York	14,165,418	6,789,694	253.2	10,758,427	5,294,689	168.9	2,519,000	1,186,100	50.4	5,083,103
North Carolina	6,732,813	3,171,622	259.1	5,354,259	2,676,252	358.1	1,701,440	816,830	74.7	3,102,386
North Dakota	3,442,748	3,261,988	261.5	427,380	237,794	57.5	69,522	37,236	6.8	5,124,010
Ohio	8,501,387	4,164,400	101.7	7,067,322	3,524,632	70.1	2,481,840	1,180,620	27.0	8,771,620
Oklahoma	6,925,221	3,634,955	247.6	1,782,024	941,272	54.9	1,487,800	791,645	46.7	4,509,927
Oregon	3,182,650	1,847,690	110.7	2,279,649	1,371,417	101.1	336,707	203,360	24.3	2,658,316
Pennsylvania	8,552,728	4,189,606	141.8	8,240,284	4,085,272	83.5	3,021,523	1,374,739	25.0	5,704,821
Rhode Island	1,179,290	589,645	16.4	390,482	195,241	3.5	63,560	31,780	.6	1,507,383
South Carolina	5,361,442	2,369,848	266.5	2,860,644	1,276,376	86.2				2,494,519
South Dakota	2,016,762	1,128,306	246.1	4,562,779	2,523,300	441.5	339,070	187,490	27.8	4,197,395
Tennessee	5,464,890	2,701,644	176.7	3,688,369	1,844,906	70.6	855,100	427,550	25.5	5,255,382
Texas	12,810,955	6,329,343	831.5	14,654,135	7,236,356	674.5	2,222,925	1,078,405	165.2	8,384,100
Utah	1,103,182	751,269	107.2	2,156,413	1,530,240	73.5	315,490	225,715	10.2	1,451,399
Vermont	1,285,741	592,143	33.9	722,784	343,793	17.7	200,670	100,095	4.3	643,793
Virginia	6,032,458	3,006,178	211.3	3,055,916	1,524,398	84.1	945,342	472,086	18.6	2,046,566
Washington	4,034,336	2,070,107	99.8	2,782,766	1,456,550	35.7	438,711	228,400	2.9	2,045,645
West Virginia	1,865,812	1,320,896	66.7	1,545,172	773,511	36.8	367,170	183,585	13.1	3,097,108
Wisconsin	5,069,889	2,502,304	176.2	6,981,719	3,272,880	183.4	81,482	37,000	.1	3,507,281
Wyoming	2,543,348	1,537,940	281.4	1,005,002	617,501	96.0	344,330	191,450	23.4	1,380,886
District of Columbia										487,500
Hawaii	809,490	396,078	18.0	856,440	419,895	9.4	484,577	239,928	8.9	1,462,820
Puerto Rico	189,737	92,320	4.4	1,591,031	790,985	32.4	568,259	281,430	10.8	557,140
TOTALS	214,621,244	110,079,295	8,708.9	189,066,281	94,208,664	6,027.7	57,575,577	28,656,481	2,111.2	165,836,894

U. S. GOVERNMENT PRINTING OFFICE: 1939

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MARCH 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 247,610	$ 247,411	6		4	$ 1,229,179	$1,227,324	15	1	1	$ 8,700	$ 8,700			2	$ 895,106
Arizona						231,874	229,670	3								526,004
Arkansas	405,664	403,606	9			296,955	296,675	6			104,053	104,053	2			1,298,166
California	1,086,722	1,086,147	4	2		1,652,737	1,652,137	8	1		444,118	443,623	4			1,247,158
Colorado	32,475	29,087	1		2	266,218	266,218	4			344,269	340,508	2		19	903,714
Connecticut						18,930	12,665									998,900
Delaware	39,000	39,000			13	47,420	47,420	2		10						504,830
Florida	10,616	10,616				434,894	434,894	3			79,700	79,700	1		1	1,158,058
Georgia						436,400	436,400	7			103,670	103,670	2	1	3	2,354,600
Idaho	174,973	174,800	4			280,682	249,386	4			131,898	120,500	1			439,963
Illinois	369,500	369,500	2		1	2,260,325	2,260,325	16	2	63	943,740	875,740	5	1	16	2,729,861
Indiana	690,434	597,473	3	5		895,391	868,491	3	1	90	164,640	164,640		1	8	1,298,044
Iowa	1,037,085	1,003,364	10	2	20	204,947	192,900	3			209,134	174,706	9		1	1,742,059
Kansas	532,239	532,134	8		4	959,403	959,403	12		1	157,405	157,405	2		8	1,430,525
Kentucky	145,000	145,000	1			449,315	449,315	5	1	31	357,864	357,864	5	3		1,218,712
Louisiana	11,980	11,980				435,221	428,478	4			429,826	398,090	10			1,049,379
Maine	48,590	48,590	2			332,396	332,396	3	2		147,150	147,150	1	1	1	298,258
Maryland						72,188	72,188	1			18,200	18,200			4	1,137,108
Massachusetts	54,710	54,710		1		296,298	295,577	1	2		282,055	281,205	1	2		1,690,082
Michigan	930,783	924,372	8	1	35	588,806	588,806	5	2	10	181,900	181,900	1			2,239,254
Minnesota	39,556	39,556		1	1	760,185	759,864	3	5		17,059	17,059			3	2,154,213
Mississippi	253,500	253,500	3			538,860	538,860	6	1		145,460	145,460	2			956,981
Missouri	297,091	295,552	4	1		447,800	447,800	2	1		1,026,220	959,930	4	2		1,918,155
Montana	355,586	350,704	4			634,520	634,520	6			235,773	235,773	3			364,726
Nebraska	147,408	147,319	4			757,788	757,788	16			618,287	618,287	16		33	588,705
Nevada	153,254	153,254		3	3	199,098	199,098	1	1		27,858	27,858			6	176,363
New Hampshire	70,205	69,765		1	2	87,856	87,797	5		1						433,688
New Jersey	116,891	111,665	1	1		229,856	229,856	1	1	2	373,470	351,050	1	1		1,667,300
New Mexico	168,984	168,984	4	1		118,994	118,994	3			87,240	87,240	2		1	643,230
New York	992,501	991,800	4	3	2	1,798,751	1,790,301	5	8		362,704	361,554		3	1	4,962,223
North Carolina	121,550	121,550	1	1	1	1,308,960	1,273,860	8	7		330,660	330,660	2		37	1,219,301
North Dakota	209,450	208,387		1		639,692	591,290	4	1							1,088,708
Ohio						539,740	539,740	6	1		412,640	371,640	5		2	4,151,641
Oklahoma	40,774	30,792			4	272,865	238,865	2		28	89,870	89,870			23	2,377,023
Oregon	308,391	307,742	1	2		384,601	250,242	1			167,455	167,455	2			484,121
Pennsylvania	213,129	197,923	2			1,301,403	1,089,504	2	1		690,222	690,222	2	1		4,883,502
Rhode Island						438,791	438,791	1	3							152,459
South Carolina	47,906	47,456	1	1		335,743	281,227	14	1	2	503,729	503,729	4	1	38	950,440
South Dakota	129,150	128,517	2		9	271,930	271,930	3	2		38,490	38,490	2		7	1,149,978
Tennessee	2,660	2,660			1	323,510	323,510		3	1	486,890	486,890	3		7	1,452,160
Texas	226,560	225,627	6	2		1,920,887	1,889,692	20	4		1,102,061	1,035,830	11	1		3,280,829
Utah	101,648	101,648	2		4	47,359	47,359	2			201,460	201,460			77	352,070
Vermont	237,610	226,469	6	2	6	10,176	10,176			1	25,490	25,300			8	316,007
Virginia	329,409	328,336	13	1		603,632	514,632	9	2	1	362,737	362,737	3	1	23	966,958
Washington	247,816	236,347	2	3	2	822,574	821,164	11	1		86,637	86,637		1	13	541,588
West Virginia	218,401	217,381	1		3	308,341	292,581	3			103,800	103,800	4		3	971,052
Wisconsin	202,131	200,987	3			1,186,812	1,145,988	11			18,119	18,119			4	1,594,489
Wyoming	164,037	164,037		2	4	10,150	10,150				214,610	135,190	1	1	7	499,487
District of Columbia						30,215	30,215		1		283,544	243,750	1			148,966
Hawaii						201,200	201,200	3	1		29,220	29,220	2			360,830
Puerto Rico	24,930	24,780	1			189,639	188,590	3			69,730	69,160	4			597,846
TOTALS	11,237,909	11,030,528	123	37	121	28,111,507	27,316,252	256	57	242	12,219,757	11,752,024	120	21	356	66,564,820

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MARCH 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 234,900	$ 117,450	18.4	$ 834,850	$ 412,050	38.6				$ 833,746
Arizona	389,951	252,338	25.4	131,384	92,415	16.9	$ 65,551	$ 47,266	.1	477,973
Arkansas	13,126	6,563		309,841	307,495	32.8	252,870	252,096	35.7	553,341
California	1,507,713	850,893	104.6	984,513	511,412	38.8	372,927	194,930	11.4	859,674
Colorado	871,019	456,096	52.1	402,820	223,165	18.3	220,370	113,009	7.8	400,486
Connecticut	69,450	34,705	1.3	46,934	23,267	.2	196,130	68,495	2.9	285,414
Delaware	18,950	9,475	4.0	50,830	25,415	10.0	35,110	17,555	8.7	267,555
Florida	20,122	10,061		516,233	257,300	12.1	275,700	137,850	14.2	469,894
Georgia	374,181	176,800	50.6	579,226	289,613	71.6	170,780	85,390	23.4	1,083,775
Idaho	453,367	203,954	46.9	166,441	87,870	11.9	24,812	14,825	1.1	351,190
Illinois	1,667,341	829,836	146.2	1,381,632	636,816	70.4	412,500	197,750	29.4	970,920
Indiana	663,404	277,092	75.8	752,100	367,050	60.6	584,947	270,708	50.0	691,475
Iowa										1,679,807
Kansas	163,626	81,812	14.8	119,236	59,618	10.1	407,036	203,518	39.8	1,361,899
Kentucky	791,832	245,084	106.1	701,106	181,576	23.0	899,303	254,970	96.2	410,817
Louisiana	75,038	37,385	6.9	727,208	313,890	57.1	361,231	167,160	31.8	421,213
Maine	356,142	176,677	23.3	262,662	126,214	12.5	27,500	13,750	2.1	148,402
Maryland				137,974	68,987	11.2	197,900	74,855	14.2	391,839
Massachusetts				149,794	74,781	2.4	285,020	141,680	5.8	636,262
Michigan	409,561	203,281	37.0	834,004	417,002	49.7	589,700	285,150	28.6	1,082,055
Minnesota	280,898	131,160	42.2	602,574	299,243	43.0	204,248	102,124	19.5	1,252,678
Mississippi				299,000	149,500	23.8	44,700	22,350	17.0	979,016
Missouri	419,599	202,330	53.0	468,200	212,720	42.6	571,290	259,650	91.9	838,936
Montana				27,601	15,525		108,276	61,272	10.8	1,263,096
Nebraska	514,620	254,044	86.8	569,244	277,801	100.1	333,810	164,030	64.3	608,583
Nevada	425,929	347,472	68.8	120,169	104,184	15.5	26,563	23,035	1.6	212,555
New Hampshire	223,514	110,923	6.0	60,759	29,708	2.3				179,369
New Jersey	123,040	61,520	2.4	199,860	91,195	2.7	240,733	120,085	7.4	598,178
New Mexico	643,196	392,281	42.1	539,108	328,795	35.8	104,195	60,990	5.6	264,000
New York	2,309,275	1,125,396	166.3	1,899,000	949,500	99.6				1,014,487
North Carolina	699,564	349,170	77.3	904,564	452,260	80.1	180,740	77,950	20.9	551,003
North Dakota	51,622	27,362	9.0	169,910	90,999	26.1	42,770	22,907	8.2	875,809
Ohio	147,535	73,767	3.8	184,690	99,120	7.0	463,440	231,720	26.8	1,964,512
Oklahoma	302,203	160,942	35.8	158,054	84,098	7.1	602,040	297,148	32.4	990,316
Oregon	453,217	263,260	58.5	112,895	68,402	16.1	428,567	257,210	45.2	414,485
Pennsylvania	1,706,116	811,798	123.1	1,789,367	876,902	97.5	638,704	319,352	32.4	742,892
Rhode Island	66,840	33,420	3.5	194,923	97,438	5.8	74,070	37,035	.9	93,123
South Carolina	404,550	174,382	43.5	834,787	349,369	90.5	190,290	75,500	14.4	278,661
South Dakota	11,519	6,250								1,058,050
Tennessee	259,120	129,560	14.8	680,124	267,162	29.7	29,600	14,800	.3	959,938
Texas	2,877,833	1,301,941	398.4	2,115,674	1,008,898	225.1	793,300	355,476	100.7	1,392,517
Utah	450,730	230,606	41.1	335,512	170,870	27.0	98,150	53,444	13.5	264,160
Vermont	238,385	109,790	13.8	90,306	45,153	4.0	43,300	20,500	.5	107,278
Virginia	571,647	246,135	61.5	810,552	392,809	65.4	150,970	75,485	14.4	450,299
Washington	549,807	286,426	63.7	656,998	345,296	39.0	100,414	52,700	3.3	280,706
West Virginia	247,154	122,025	21.4	153,296	76,648	8.3				513,306
Wisconsin	557,666	265,848	23.1	656,279	322,660	32.0	146,298	69,640	2.5	916,888
Wyoming	416,281	254,565	59.0	321,002	198,349	15.8	85,578	52,861	6.5	266,775
District of Columbia										73,125
Hawaii				68,130	34,065	2.4	124,850	62,425	3.5	223,510
Puerto Rico	224,621	110,876	11.3	131,605	64,530	8.8	55,188	27,140	2.1	117,454
TOTALS	23,256,204	11,552,751	2,243.6	24,242,971	11,979,135	1,701.3	11,261,471	5,457,786	949.8	33,123,442